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EXPERTISE IN THE FUTURE USE  
OF GENERIC TECHNOLOGIES

- Epistemic and Methodological  
Considerations Concerning  
Delphi Studies

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**Abstract:** In 1990s there has been a "boom" of extensive technology foresight studies based on the use of the Delphi method. This study examines critically e.g. national foresight studies made in Japan, Germany, the United Kingdom and Austria. The study suggests that the epistemic paradigm of the general theory of consistency (GTC), presented in the book, can provide working epistemic foundations for futures studies and for technology foresight Delphi studies in special. Results of the national foresight exercises are examined with an epistemic utility model based on GTC. The epistemic utility is a modification of the traditional utility concept of investment theory. New conceptual tools are used for the analysis of the expertise and information policies of different expert groups in technology Delphi studies. Empirical background of discussion are three technology Delphi studies made by the author. They concerned use of computer based information services of households, new biotechnology and the material technology. Based on these studies a special interpretation of the Delphi method is provided: the Argument Delphi.

**Key words:** technology foresight, Delphi, futures, innovation, argumentation  
**JEL classification:** O3, D8

**Tiivistelmä:** 1990-luvulla on tehty monia laajoja Delfoi-tutkimuksia teknologian tulevasta kehityksestä. Tutkimus arvioi kriittisesti mm. Japanin, Saksan, Englannin ja Itävallan kansallisia tutkimuksia. Kirjassa ehdotetaan, että siinä esitetty yleinen konsistenssiteoria (YKT) voi tarjota käyttökelpoisen tietoteoreettisen perustan tulevaisuudentutkimukselle ja erityisesti teknologian kehitystä ennakoiduille Delfoi-tutkimuksille. Kansallisten teknologian ennakoitihankkeiden tuloksia on tarkasteltu tiedon kasvua ja oikeellisuutta korostavalla utiliteettimallilla, joka modifioi investointiteorian perinteistä hyötykäsitettä. Uusia käsitteellisiä työvälineitä käytetään teknologisten Delfoi-tutkimusten asiantuntijaryhmien asiantuntevuuden ja tiedon luovuttamiskäytäntöjen tarkasteluun. Tutkimuksen empiirisenä taustaineistona ovat tekijän kolme Delfoi-tutkimusta. Ne käsitelivät kotitalouksien tietoverkkopalveluja, uutta biotekniikkaa ja uutta materiaalitekniikkaa. Tekijä ehdottaa tutkimustensa pohjalta uutta tapaa tulkita Delfoi-tekniikka ("Argument Delphi").

**Asiasanat:** Teknologian ennakointi, Delfoi, Delfi, tulevaisuudentutkimus, innovaatio

**JEL luokittelu:** O3, D8



## PREFACE AND ACKNOWLEDGMENTS

This study intersects many research areas or research paradigms: futures studies, innovation research, economics, management science, philosophy, semiotics, social psychology and neurosciences. The study is an attempt to combine general epistemic and methodological considerations and the author's practical expertise in technology foresight Delphi studies and in futures studies.

All different research paradigms give their interpretation to a key concept of the study: *technology generalization*. According to Nobel laureate neurophysiologist Gerald Edelman (1989, 27-31) animals can *generalize*; that is, an individual organism can encounter a few instances of a category under learning conditions and then recognize a very great number of related but novel instances. Main research questions of this study are: *Who and in which conditions are able to anticipate reasonable technology generalizations? Who and in which conditions are motivated to inform about reasonable future technology generalizations?*

The epistemic considerations of the study are the result of a long intellectual process. The basic ideas of the general theory of consistency and the types of reasonable argumentation have developed step by step during more than three decades. Besides virtual discussions with many thinkers - Georg Edward Moore, Eino Kaila, Ludwig Wittgenstein, Georg Henrik v. Wright, Thomas Kuhn, Umberto Eco, Fernidand de Saussure, Algirdas Greimas, Ian I. Mitroff, Jürgen Habermas, Gerald Edelman and Bertrand de Jouvenel - discussions with friends and colleagues have been decisive. My epistemic paradigm has been developed in these discussions. Besides futures researchers and innovation researchers who will be mentioned below I would like to thank my friends and colleagues in semiotics and philosophy Eero Tarasti, Hannu Riikonen, Henry Broms, Kari Salosaari, Antti Hautamäki, Marja-Liisa Kakkuri-Knuuttila and many others. Especially I have always admired Ilkka Niiniluoto's intellectual rigor.

I have interviewed over one hundred experts in my different technology Delphi studies. I have very much learned from these interviews and I like warmly thank all experts for their contributions. The interviews and further comments of experts is the main basis of my practical expertise, though I also have had other common activities especially with small innovative enterprises. The other Delphi

managers beside me - Liisa Viikari, Mervi Sibakov, Irina Aho-Mantila, Veikko Komppa, Heikki Kukko and Arto Mölsä - had a special burden in my technological education. I would like to thank especially Mervi Sibakov also for her help in the formulation of the paradigm of the new biotechnology. She is, of course, not responsible for the outcome.

This study is made especially with the communities of futures and innovation researchers and for them. Wendell Bell has given me essential and encouraging comments concerning the general theory of consistency. Annele Eerola, Hannele Kuusi, Hannu Linturi, Torsti Loikkanen, Pentti Malaska, Mika Mannermaa and Ahti Salo have provided me with useful material and comments. Especially I like to thank Jari Kaivo-oja and Martin Meyer for their support and help.

I would also like to thank all other friends and colleagues in the Finnish society for futures studies and the Finland Futures Research Centre at Turku. I name only some: Olavi Borg, Jarl-Thure Eriksson, Sirkka Heinonen, Iiris Hämäläinen, Jarmo Hukka, Janne Hukkinen, Vuokko Jarva, Jyrki Kettunen, Torsti Kivistö, Meimi Lahti, Matti Leskinen, Tarja Meristö, Jari Metsämuuronen, Keijo Mäkelä, Juha Nurmela, Mika Pantzar, Tapio Rantala, Anita Rubin, Veikko Salovaara, Timo Sneck, Markku Sotarauta, Sari Söderlund, Paula Tiihonen, Matti Vapaa-vuori, Marja-Liisa Viherä and Markku Wilenius. I hope that this study is a bridge between futures studies and innovation studies. I hope that the cooperation with Ian Miles, Bengt-Åke Lundvall, Gerd Schienstock, Tarmo Lemola, Ilkka Tuomi, Pekka Ylä-Anttila, Jari Romanainen, Timo Hämäläinen, Sirkku Kivisaari, Erkki Ormala and E-O Seppälä and many others will continue successfully.

My warmest thanks go to my supervisor Risto Tainio who has read many versions of the study and with patience guided me towards more empirical considerations. His many comments as well as the comments of Kari Lilja have been invaluable. Raimo Lovio introduced me to the community of scholars in the Department of Management and Organization at the Helsinki School of Economics and Business Administration. Thanks for it. David Miller have helped me to express my thoughts in English. Any remaining errors and lack of fluency are of course entirely due to me.

Last but not least I would like to give special thanks to VATT, the Government Institute for Economic Research, which have financed my studies. VATT and its predecessor TASKU have provided challenging research environments of my studies. I would like to thank my earlier superiors Eero Tuomainen and Seppo Leppänen and the present superior Reino Hjerppe and all my research colleagues, especially Antti Romppanen and Leena Saarinen for help in all phases of the study. Helinä Silén have assisted in editing the text of this book. The integration of economics and futures studies/innovation studies is a challenging task. I would like to thank especially Esko Niskanen, Jouko Kajanoja, Seija Parviainen and Pia Koskenoja for interesting discussions concerning this topic.

Finally, warm thanks to my wife Hannele for the patience during my long working days. I hope that I have been able to give at least an intellectual challenge to my sons Tuomo, Tero and Touko.

Osmo Kuusi

Helsinki, September 1999





## SUMMARY

An important goal of this study is to analyse how expert knowledge could be relevant for foresight on innovations (or generalizations) based on generic technologies. A "generic technology" opens up a wide range of possibilities for further innovations in many sectors of economy (compare Martin 1996, 1).

Another focus of the study is to suggest new epistemic or philosophical foundations for futures studies. As Bell (1997 I, 166-167) has remarked, epistemology has remained one of the least developed aspects of futures studies:

Despite a few efforts, such as those of de Jouvenel (1967), Helmer and Rescher (1960), Mitroff and Turoff (1975), Ogilvy (1992), Scheele (1975), Masini (1981,1982,1993) and a few other futurists, epistemology remains one of the least developed aspects of futures studies. There is irony in this fact, since methodology - specific research tools and techniques - to the contrary, is one of the most developed aspects of the field, and there are, of course, implicit epistemological assumptions and commitments that necessarily underlie every method.

The critique of Bell is directed to the Delphi method, as well as at other methods. The Delphi method is probably the most often used method in technology foresight studies made by futurists.

The discussion in this study proceeds from the general epistemic questions of futures studies to the specific problems of technology foresight Delphi studies. In the 1990s, there has been a "boom" of extensive technology foresight studies based on the use of the Delphi method. My analysis is much based on the critical examination of these studies and especially foresight studies made in Japan, Germany, the United Kingdom and Austria (Delphi Report Austria 1998, Cuhls 1998, Cuhls et al. 1998, NISTEP 1997, Georghiou 1996, Elliott 1996, Cuhls et al. 1996, Loveridge et al. 1995, Cuhls and Kuwahara 1994, Grupp 1993, Grupp 1993b).

The empirical background of discussion comprises three technology Delphi studies made by the author. Each of them used different methodology than the national studies. The studies concerned use of computer-based information serv-

ices of households (Kuusi 1987, 1991b), new biotechnology (Kuusi 1991) and new material technology (1994). Before this study, the results of these Delphi studies have been available only in Finnish.

My examination is mostly methodological. Different chapters of the book are focused on different methodological problems of Delphi studies. The chapters can be seen as rather independent essays, which are loosely interconnected. Chapter 1 is the most general one. It suggests an epistemic paradigm. I consider that the epistemic paradigm of the general theory of consistency (GTC), which was originally presented by Kuusi (1974), can provide working epistemic foundations for futures studies in general and especially for technology foresight Delphi studies. Technological paradigms and their "developer communities" are the focus of Chapter 2.

Chapter 1 and Chapter 2 provide starting points for Chapter 3. In Chapter 3 two main theoretical contributions<sup>1</sup> of this study are presented: the epistemic utility model and three basic types of reasonability of technology foresight studies: predictive, option and commitment reasonability. In Chapter 3, I also present basic features of the Argument Delphi, which might be the most important practical contribution of the study.

The epistemic utility model, the three types of reasonability and the Argument Delphi are the background of Chapter 4, which discusses group communication aspects of the Delphi method. At the end of this chapter, I make methodological conclusions concerning the future use of the Delphi method in technology foresight studies. Chapter 5 discusses the typical types of expertise and information policies of different expert groups in a technology Delphi (for example typical biases in judgments and arguments). Chapter 6 looks at methodologically interesting aspects of the Argument Delphi based on my experiences and on results of the three technology Delphi studies in which I have been the Delphi manager. Final conclusions are presented in the chapter seven.

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<sup>1</sup> I of course consider that the general theory of consistency is also an important theoretical contribution. It is published for the first time in English in this dissertation.

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# **1. EPISTEMIC FOUNDATIONS OF KNOWLEDGE ABOUT THE FUTURE**

## **1.1 The Oracle at Delphi and the Anticipatory Rationale**

The name of the Delphi method is a half-ironical reference to an ancient appreciated "experts" on the future: the oracles of Apollo at Delphi or Pythiae. The "divine madness" of the Pythia (based perhaps on drugs) was evidently generally<sup>1</sup> recognised to be one kind of expertise about the future. "Divine madness" or plain talk to authorities, without taking into account the possible consequences of hard words, have been a distinctive sign of a believed prophet. Henri Troyat (1984,126-127) tells in his biography of Ivan the Terrible, the Tsar of Russia (1547-1584), how a prediction saved Pskov from destruction. After cruel terror in Novgorod based on erroneous suspicions of conspiracy with Poland, Ivan and his army entered Pskov, the other "conspiracy" town Pihkova:

Troyat tells that Ivan decided to visit in a cell of a monk, Nikolai, who saw visions. Ivan met a half-naked, thin, wild-looking, unshaved man with a necklace. The man gave him a piece of raw meat looking at him impudently and arrogantly. "I am Christian", the tsar said to him, "I do not eat meat during the great Lent". The hermit answered firmly: "You do bad things: you eat human blood and meat, you do not forget not only the Lent but the God". He predicted to the tsar that he would be struck by lightning, if he would move even a hair of child in Pskov. At the same time black clouds covered the sky. The tsar heard a distant clap of thunder. For safety's sake Ivan ordered his army to leave the town, because the God likes to express Himself through the mouths of simple (Mad of Christ).

Was the monk an expert about the future? That is a tough epistemic question which I will discuss in chapter 3. If the defining feature of an expert about the future<sup>2</sup> is that he or she is able to produce relevant arguments concerning the fu-

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<sup>1</sup> The "father of history" Herodotos refers in many connections in his book History to the answers of the oracle at Delphi. Actually he refers to many oracles. According to Herodotos (the Book I, 47-49, Herodotos 1907, 24-25) the king of Lydia, Kroisos, even tested the predictions of different oracles. He realized that the oracle at Delphi was the best in "prediction reasonability".

<sup>2</sup> According to Jarvis (1990) an expert is a person, who based on the evaluation of the peer group and has some special knowledge or skills. An important feature in this definition is that the expertise is

ture, I consider that the monk was an expert in one specific sense: his viewpoints were important in terms *predictive reasonability* because he was capable of making arguments which had an impact on the realized future. Let us suppose that the monk would not have believed in his prediction if he had all the information we now have. In that case, on the basis of the *option reasonability* or *commitment reasonability* the monk was not an expert.

The idea that expertise about the future includes also influence on history was current already in the time of Pythia. Archaeological discoveries and historical investigations (e.g. Parker 1956, Cuhls and Kuwahara 1994,5) have made it clear that the oracle was not only intended to predict the future but to guide and direct the world's history at that time.

The place name "Delphi" comes from the dolphin into which Apollo changed himself according to Greek mythology in order to hire the first oracle priests, who were mariners. The mythology stresses the role of other types of experts behind the Pythia, namely the team of priests. The assisting priests had, however, more specific (and as we now see more reliable) expertise, which was used both in everyday problems and in state questions. It is interesting that the first priests were assumed to be mariners. Mariners had perhaps the most extensive (or the best *synthetic*) knowledge about different cultures in that time.

As the whims of a moment or irrational beliefs have often impact on even the most important decisions affecting the future, so is also the logic behind important scientific discoveries often very complex. Irvine and Martin (1989,13) consider that there are certainly many who, while accepting the need for research foresight, nevertheless doubt whether such an endeavor is possible in practice. 'You cannot forecast science or technological innovations - they are too unpredictable' is likely to be their reaction. The response to this objection by advocates of foresight is well summed up in Bright's rhetorical question: 'Does it make sense to commit a nation's research resources on the basis of total inexplicability and lack of an anticipatory rationale?... Are we content to be "scientific" about everything but science itself?' (Bright 1986, 1 and 12).

The concept "anticipatory rationale" is more modest and feasible for the epistemology of expertise about the future than the concept "forecasting". The expertise in anticipation or foresight involves an explicit recognition that the choices made today (sometimes by anticipating experts) can shape or create the future, and that there is often little point in deterministic predictions in spheres

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socially acknowledged (Remes 1995). My idea is that acknowledgement of expertise about the future is based on three types of qualifications: true predictions or predictions having an impact on the realized future (prediction reasonability), options which are feasible from the point of view of some well-informed actor (option reasonability) and a plan which is feasible and realistic for a group of well-informed actors, who take into account each other's actions (commitment reasonability).



(including technology) where social and political processes exercise a major influence.

The purpose of this first chapter is to look for the epistemic foundations of "anticipatory rationale". What is the relationship between "truths as building blocks of the future" and different theories of truth? The chapter ends with a presentation of the basic elements of the general theory of consistency (GTC) and a paradigm for future studies based on it. I hope that the future will show that this paradigm is an important contribution to the epistemology of "anticipatory rationale".

## 1.2 Three Theories of Truth

Niiniluoto (1987, 134) considered that traditionally, the most important theories of truth have been the correspondence theory, the coherence theory and the various versions of the pragmatist theory.

According to *the correspondence theory*, truth is a relation between a belief and reality. In this account, the bearers of truth are considered the sentences, statements, judgments, propositions, beliefs or ideas; they are true to the extent that they "correspond" to reality, the world or facts. A statement is a description of a "possible state of affairs". It is true if the state of affairs is "actual" or exists in the "real world", that is, if it expresses a "fact"; otherwise it is false.

The idea behind the correspondence theory is that there is a stable "real world". The purpose of science is to find the stable features of reality. According to Charles Peirce

a (scientific) method should be found by which our beliefs may be determined by nothing human, but by some external permanency - by something upon which our thinking has no effect (Peirce, 1931-35, 5.384).

Scientific method supposes:

There are Real things, whose characters are entirely independent of our opinions about them; those Reals (realities) affect our senses according to regular laws, and, though our sensations are as different as are our relations to the objects, yet, by taking advantage of the laws of perception, we can ascertain by reasoning how things really and truly are; and any man, if he has sufficient experience and he reasons enough about it, will be led to the one True conclusion (Peirce, 1931-35, 5.384).

The truths of scientific correspondence theory are *objective* in the following sense (Niiniluoto 1980, 83):

- a) The truths concerning the features of an object are independent of the opinions of the researcher.
- b) Scientific knowledge arises in interaction between a researcher and the object of study.
- c) Truths cannot be based on dogmas, beliefs, revelations, authorities or intuitions. In the final analysis, the source and criterion of knowledge is direct evidence concerning the object of study.
- d) There is a possibility to reach truthful knowledge about the object of study and a research community can become unanimous about the quality of the knowledge.

According to Niiniluoto (1987, 135), *the coherence theory* claims that a judgment cannot "correspond" to any extralinguistic reality; truth has to be defined in terms of the relations that judgments bear to each other. Thus, a judgment is true if it forms a coherent system with other judgements. Although some prominent modern philosophers like Nicholas Rescher and Otto Neurath have defended the coherence theory, Niiniluoto considered that coherence, understood as some sort of consistency, is not an adequate definition of truth.

In ordinary logic, the condition that a sentence A is compatible with a consistent set X of true sentences, is not sufficient to guarantee the truth of A. Still, this condition is necessary for the truth A. Otherwise, one contradicts the rule of logic that  $X \& A$  cannot be true at the same time as  $X \& \neg A$ . According to Niiniluoto the compatibility is not enough for the truth, because it may happen that neither A nor  $\neg A$  follows from X.

A simple example concerning the truths of the future illustrates, what Niiniluoto means. Suppose that a researcher tried in 1982 to predict how many mobile telephones would be in use in Finland in 1995. One can make a list of truths, that explain the real number (about one million) and were already known in 1982: the NMT (Nordic Mobile Telephone) system was just started; first relevant applications (or generalizations) of the digital technology were made; and Finns were driving more cars. It is at least in principle possible to make a long list of truths like those, from which one could infer the right prediction. The problem is that an evaluator can never be sure that he or she has enough items in his or her list. For example based only on the above three truths, one could rationally claim several figures for the numbers of mobile phones in Finland in 1995.

The third theory of truth is *pragmatism*. According to Niiniluoto (1987, 136) pragmatists think that it is not meaningful to speak of truth and reality as divorced from human practical and cognitive activities. The reality as such of the correspondence theory is replaced by reality for us (truth-as-known-by-us). Truth

is defined in terms of the results of human knowledge seeking: true means the same as "proved", "verified", "warranty assertive", "successful", or "workable" in practice, the ideal limit of scientific inquiry. A present formulation of the program is made by Jürgen Habermas: the ideal consensus is reached in "free" or "undistorted" communication.

Like correspondence theorists, many contemporary pragmatists have also been inspired by Charles Peirce. Peirce has characterised truth as the ideal limiting opinion of the scientific community. Richard Rorty has interpreted Peirce so that "we can make no sense of the notion that the view which can survive all objections might be false". The correspondence theorist Niiniluoto thinks that the phrase "all objections" must refer to situations where the scientific community has access to all true statements about the world. Without such access to at least some truths about reality, there is no guarantee that a community of investigators reaches the correct solution even to the simplest cognitive problems - whatever standards of discourse rationality we may impose on the communication between its members (Niiniluoto 1987, 137).

### **1.3 Truths about the Future**

The possibilities of achieving objective knowledge concerning the future are limited, if we accept the criteria of objectivity given by Niiniluoto above.

Truths concerning the future are often not independent of the opinions of the researcher, because the researcher can still have an impact on the decisions which shape the future. A researcher cannot have a direct contact with the object of study in the future. The contact is based on the cues in the past. It is, however, good to notice that also many scientific objects in the past and in the present are only indirectly attainable. Many elementary particles of nuclear physics are "observable" only by using very complicated monitoring instruments and happenings in the past are possible to construct only by using present cues.

Norms, dogmas, beliefs, revelations, authorities and intuition have some role in the shaping future, because they affect decisions concerning the future. But in a similar way they are also important explanations of the past. It is seldom possible that a research community can become totally unanimous about the quality of the knowledge concerning a future object, because the future object is "unfinished". If the unfinished nature of the future or the role of beliefs in the process of its formation are considered to make the anticipation unscientific, then very many explanations of the past made by historians are unscientific.

I will start my search for a new kind of scientific epistemology of knowledge about the future with the profound discussion of Bertrand de Jouvenel (1967).

The analysis of de Jouvenel has provided an explicit or implicit epistemic background of many future researchers.

The starting point of the analysis of de Jouvenel were the images formed in our minds. He considered, that it is natural to call images referring to the present or past "representations", for they "represent" facts, in however subjective manner. These representations can, however, also be fiction images of future. These fictions are of major importance in our life. When we retain a fiction as something to be enacted, it serves as the source of systematic action. De Jouvenel (1967, 25-30) presented four theses:

1. Without representations, there would be no actions<sup>3</sup>, only reactions. Any behaviour which is not a necessary consequence of the external pressures acting on a man should be called an "action". Consider the ancient hero Mucius Scaevola, who deliberately held his right hand over live coals to let it be consumed. Time future is the domain able to receive as "possibilities" those representations which elsewhere would be "false". Man acts, not "because...", but "in order to..."
2. Sustained, systematic action aims at the validation of a representation projected into the future. De Jouvenel compared the projection of the image "over there" to the rock climber's flinging of a rope "up there"; in each case, the throwing comes first and enables the actor to move toward the "hitching point." But there is a difference. The fixed point of the climber exists objectively and provides physical aid, whereas a project exists only subjectively.
3. Other things being equal, an assertion about the future must be weighed according to the strength of the intention. An assertion about the future does not indicate a fact, but an intention. Intentions provide a convenient basis comparing the projects of different people. The intensity of intention, that is the mobilising of one's energy, is of great importance.
4. A man who acts with sustained intention to carry out a project is a creator of future. Ego knows he has forces at his disposal, forces he can mobilise by conscious effort to carry out a project. In this sense, the fact of my presence in New York is the consequence of my imaging myself in New York.

De Jouvenel (1967,35) considered that an individual who forms and pursues a project is generally inclined to postulate the stability of the universe. The universe is, however not generally stable. "Deformations of the social surface" are needed. How do these deformations arise? According to de Jouvenel it would be simpler to define when they do not arise. To the extent that the same repetitive

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<sup>3</sup> A technical problem in the following discussions is the sex of actor. This is not a problem of my native language Finnish, because we have a word "hän" which represents both "he" and "she". I will suppose that the learning being or the actor is "she". "She" is so the representative of the both sexes, though I in the connections where the sex matters might use "she" or "he". I think that it is useful that developers of technologies who are recently mostly men remember the increasing role of women even in these matters.

patterns and mutual relations are maintained in the behaviour of different people, the social surface is stable.

How can the future be an object of knowledge in the framework of de Jouvenel? According to de Jouvenel, we treat many aspects of the future as known, and if we did not we could never undertake any projects. The subjective certainties are the features of the future that one treats as known and does not question. This certainty may be falsified by events, but a given person does not contemplate that things could be otherwise. There are different certainties (de Jouvenel 1967, 43): "... the natural order is a datum, whereas the constitutional (for example the recurrent elections, my addition) order is a construct. The constitutional order is modifiable and can, moreover, collapse." Contractual assurances are a special form of constructs. De Jouvenel considered that a man of honour behaves in the way expected of him and as he has committed himself to do.

For a given person, the future is divided into dominating and masterable parts (de Jouvenel 1967, 52). The masterable future is what a person can make other than it now presents itself. De Jouvenel stressed an important point: " in human affairs the future is often dominating as far as I am concerned, but is masterable by a more powerful agent, an agent from a different level" (for example the state, author's addition).

As a conclusion of his analysis, de Jouvenel (1967, 53-55) distinguished between primary, secondary and tertiary forecasts. He illustrated these predictions with the considerable increase of pollution in Paris. The average inhabitant had become quite conscious of this nuisance: he expected that it would get worse and this to him is a dominating future. This is a "*primary forecast*". It represents a first stage in our dealing with the future course of a phenomenon. If there is an authority with a capacity to change the development, the primary forecast serves to challenge this authority: "This is our future, unless you take measures to amend it".

The authority has a choice of measures differing in efficiency, which it takes more or less time to bring into operation and which car users and manufacturers will regard as more or less annoying. De Jouvenel asks us to imagine that the authority is provided by its experts with a set of curves, one of which represents the "primary forecast", while each other curve pictures a more or less amended course of the phenomenon expected after this or that corrective measure. The set of these curves constitute a fan of possible futures, of *futuribles*. The preparation of any of these curves is a "*secondary forecast*". Hence, it is conditional on the taking of a certain definite action and is based on known or presumed causal relationships.

The "*tertiary forecast*" is based on primary and secondary forecasts. Its author is aware of them and proposals submitted to the authority. Now he wants to "predict" what the course of pollution will in fact turn to be. This implies a "prediction" bearing upon the behaviour of the authority. According to de Jouvenel (1967,55), it is immediately clear that this sort of forecast, which includes guesses concerning the choice and timing of unique moves by a few individuals, is most hazardous.

An intellectual undertaking or a research program based on the epistemology of de Jouvenel is commonly called "futuribles" (de Jouvenel 1967,18). The name was chosen according to de Jouvenel because it designates what seems to be the object of thought when the mind is directed toward the future: our thought is unable to grasp with certainty the "futura", the things which will be; instead it considers possible futures. De Jouvenel considers that a future state of affairs enters into the class of "futuribles" only if its mode of production from the present state of affairs is plausible and imaginable. The example of de Jouvenel was aviation. It was considered possible already in ancient times, but it became a *futurible* only when certain new facts made its development conceivable<sup>4</sup>.

A kind of generalization of the ideas of de Jouvenel is the "strategic prospective" of Michel Godet (1994). According to Godet (1994, 36-37), the prospective approach accepts that there is a multiplicity of possible futures at any given time and that the actual future will be the outcome of the interplay between the various protagonists in a given situation and their respective intentions. How the future evolves is explained as much by human action as by the influence of causalities. Like de Jouvenel, Godet considered that the future is explained not only by the past but also by the image of the future imprinted upon the present.

According to Godet (1994,105):

The actors... possess various degrees of freedom which they will be able to exercise, through strategic action, in order to arrive at the goals they have set themselves, and thus successfully carry out their project. From this, it follows that analysis of these actor's moves, confronting their plans, examining the balance of power between them (in terms of constraints and means of action) is essential in order to throw light on strategic issues and the key questions for the future (which are the outcomes and consequences of foreseeable battles).

The ideas of de Jouvenel got a kind of practical interpretation in the action theory of Godet. The definitions which he has given to some basic concepts of futures

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<sup>4</sup> My concept "(perceived) interest" in the General theory of consistency (Appendix 1) has nearly the same meaning as "a *futurible*", which an actor tries to validate. An interest is based on the idea that its realization belongs to the capacity (and of course capability ) limits of the actor.

studies are interesting also from the point of view of technology foresight (Godet 1994, 59):

An *event* is an abstract entity whose only characteristic is to happen or not to happen. An event can be considered as a variable taking only one of two values, in general "1" if the event happens, and "0" if the event does not happen.

*Actors* are those who play an important role in the system through variables which characterise their plans and which they, to some extent, control. Example: the consuming countries, the producing countries, the multinationals

A *strategy* is a set of tactics (set of conditional decisions) determining each actor's acts relative to his plan under every possible contingency.

A *conflict* may result from the confrontation between opposing strategies of the actors, and may take the form of an outbreak of tension between two trends (overcrowding and lack of space, constrained time and free time). The outcome of these conflicts determines the evolution and the balance of power between actors or strengthens the weight of one trend or another.

An *invariant* is a phenomenon assumed to be permanent up to the horizon studied. Example: climatic phenomena.

A *Strong trend* is a movement affecting a phenomenon in such a way that its development in time can be predicted. Example: urbanisation.

A *germ* (or a *weak signal*, my addition): a factor of change hardly perceptible at present, but which will constitute a strong trend in the future. Godet cited Pierre Masse (1965): "A sign which is slight in present dimensions but huge in terms of its virtual consequences"

*Randomness*: any event in the past or future of which we possess only partial information: we are incapable of verifying whether the event took or will take place.

Irvine and Martin (1989,15) considered that essentially the Anglo-Saxon notion of (technology) foresight has a similar philosophical starting point as "la prospective" of Godet. Whereas predictive forecasting implies a rather passive attitude towards the future, foresight and "la prospective" involve a much more active stance - reflecting a belief that the future is there to be created through the actions we choose to take today. Irvine and Martin consider that the concept of (technology) foresight and "la prospective" share several features:

1. In both, the aim is not so much to predict the details and timing of specific developments as to outline the range of possible futures which stem from alternative sets of assumptions about emerging trends and opportunities.

2. Besides enabling different possible futures to be explored, they provide a means of clarifying the scope of current action and its implications for potential developments (often identified in alternative scenarios).
3. Since the phenomena and activities subject to foresight/prospective analysis are invariably complex and interdependent, a holistic or systemic approach is essential, integrating and assessing the cross-impacts among all the constituent processes, conflicts and challenges.
4. Different actors have their own, sometimes mutually irreconcilable needs, and these will be reflected in their alternative visions of desirable futures. Socio-cultural, political and motivational factors are therefore often crucial parameters in foresight and failure to take them sufficiently into account can lead to the types of problems encountered in conventional forecasting. From this, it follows that the foresight or prospective process should be transparent to enable the underlying assumptions, analytical framework and data inputs to be subject to external scrutiny. Such openness also prevents nonconformist views from being obscured by conventional wisdom.
5. Finally, both approaches recognise that the information available to make judgements about future prospects is invariably incomplete, frequently unquantifiable and intrinsically uncertain. Consequently, a range of complementary approaches ideally needs to be employed bringing contrasting perspectives to bear on the foresight process. A method can be considered a good and useful one if it can improve coherence and stimulate imagination.

One questionable conclusion made by de Jouvenel from his epistemology is that foresight activities are not scientific. This point is expressed at least in two different connections in the book of de Jouvenel. Actually the reason why the word "conjecture" appears in the title of the book is precisely that it is opposed to the term "knowledge". De Jouvenel (1967,17) cited Jacques Bernoulli "with regard to things which are certain and indubitable, we speak of knowing or understanding; with regard to other things, of conjecturing, that is to say, opining". On the same page de Jouvenel comments on the term "futurology":

This word would be very convenient for designating the whole of our forecasting activities ("futuribles" my addition) except that it would suggest that the results of these activities are scientific - which they are not, for ... the future is not a domain of objects passively presented to our knowledge.

A similar conclusion was presented on the pages 127-128:

...forecasting will be brought into closer relationship with decision-making. Forecasts can help us to make decisions whose necessity we are already aware of, and can suggest that decisions we have not pre-



viously thought of will need to be faced... We treat forecasting as an art tied to practical needs.

This (which I will attempt to show as unnecessary) idea of futurology as an unscientific art, has been accepted by many later authors.<sup>5</sup> I think that the idea of futurology as art or as conjecturing has actually worked against the diffusion of the original ideas of de Jouvenel. If we could save futurology into the sphere of science, for example accepting the epistemology of the general theory of consistency, it would be possible to make a distinction between "anticipatory rationale" and irrational anticipations. The lack of such a distinction has considerably hindered the development of futurology. The word "futures research" has got a bad reputation. Because of the bad reputation it has been commonly replaced by the new concepts "futures research" or "futures studies".

Without the distinction between "anticipatory rationale" and irrational anticipations we cannot speak about real experts and non-experts on the future. It is interesting that de Jouvenel also in passing speaks about the experts on the future (de Jouvenel 1967,54).

Wendell Bell (1997 I, 169-170) has considered that it is more reasonable to widen the scope of science than to accept the position of de Jouvenel. Bell considers that art and the futures field distinctively involve intuition, creativity, imagination, insight, and spiritual understanding. Both involve a certain amount of subjectivity and invite originality, innovation, and invention. Both are synthetic and humanising. The conclusion that futurology is unscientific just because of above features implies that science is portrayed as having contrasting features: it is mechanical, can be produced by any number of interchangeable persons, highly technical and rigorous, rational and dehumanising, standardised or too fragmented and analytic in perspective to represent reality in all its fullness.

According to Bell, the problem is that the distinction between science and art based on the above features is false: both art and science are misrepresented in these characterisations. Firstly artists, like scientists, must learn to use their tools and to apply a set of principles in solving the technical problems they face. They must be concerned - objectively and rationally concerned - with line, colour, shape, size, texture and direction. They must exercise rigor and control. On the other hand, masterpieces of science require an extra something of intuition, creativeness, imagination or insightfulness, for example in the formulation of theories. Even beauty - a hallmark of art - may be used by scientists to choose one theory over another, other things being equal (and according to Bell sometimes even if they are not equal).

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<sup>5</sup> E.g. Annele Eerola (1990 p. 1) has taken this type of position: "Forecasting is an art. A general scientific basis for forecasting is lacking and the production of forecasts is largely based on common sense, experimental modelling and lately also empirical work."

According to Bell (1997 I, 171-173), there is, however, at least one distinction between art and science that remains and that bears on the nature of futures studies. Art can be - and often is - an illusion, a deliberate distortion of reality, perhaps even a negation of it. Art includes expressiveness, especially of the inner mental states of the artist that may be fused with his or her perceptions of the outer world. According to Bell, the key point is this: artists, although they may create representations of reality or reveal a "higher truth", which give meaning and direction to life, are *not obliged* by their commitment to art to tell the truth.

To the contrary, scientists are committed to tell the truth. According to Bell, the truth is the very heart of scientific enterprise. I consider, that truthfulness is the necessary condition for science. As I will discuss in more detail later I consider that truthfulness is, however, not the sufficient condition for science. Science has to be based on theories, that produce refutable propositions and means (or languages) for progress in the production of valid arguments.

Though it is not possible to present empirical truths concerning the future, it is possible to find truthful arguments concerning the future. A possible scientific endeavour may be to increase the validity of future relevant arguments (compare "anticipatory rationale" mentioned in the beginning of the chapter). Though scientists can tell few truths about the future, their obligation is to tell reasonable arguments concerning the future. Also, de Jouvenel clearly accepts the endeavour of increasing reasonability in forecasting as the following citation shows (de Jouvenel 1967, 277):

We are forever making forecasts - with scanty data, no awareness of method, no criticism and no co-operation. It is urgent that we make this natural and individual activity into a co-operative and organic endeavour, subject to greater exigencies of intellectual rigor.

What does the reasonability of arguments mean? The objective bases of arguments are one possible interpretation of reasonability are. Although one cannot observe the future object, one may make an agreement concerning the rules which determine the derivation of the future from the past data. Public and explicit rules (for example statistical rules) remove or hinder the effects of subjective elements in predictions for example the effects of dogmas and authorities. They connect past facts and possible future developments.

Objectivity and neutrality are not, however as such the reason for the endeavour of reasonability. Nicholas Rescher (1995) has discussed the dimensions of rationality. Rescher uses the concept "rationality" to mean virtually the same as my

word "reasonability". I prefer the concept "reasonability" based for example on the following citation of the Webster's Encyclopaedic (1996, 1107)<sup>6</sup>:

REASONABLE, RATIONAL refer to the faculty of reasoning. RATIONAL is the more technical or more abstract term, concerned always with pure reason. It is applied to statements which reflect or satisfy highly logical thinking. REASONABLE has taken on more and more the pragmatic idea of simple common sense.

Rescher introduces the concept "rationality" as follows ( Rescher 1995, 25-26):

If I want a reason at all, I must want a *rational* reason. If I care about reasons at all, I am already within the project of rationality... Irrationality - wishful thinking and self-deception - may be convenient and even, in some degree, psychologically conforming. But it is neither cognitively nor reflectively satisfactory.

Rescher considers that the rationality (or in my terminology reasonability) may be cognitive, evaluative or pragmatic. In ignoring cognitive rationality we run an avoidable risk of accepting falsehoods, in ignoring evaluative rationality the risk is to endorse inferior items and in ignoring practical rationality the risk concerns the failing to achieve appropriate ends.

The validation of rationality consists in the consideration that its violation would compromise the successful pursuit of appropriate ends... The process of validating reason pivots on there being (cognitively) sound reason to think that an (evaluatively) appropriate end of the enterprise will become less likely to be (practically) realized (Rescher 1995, 26-27)

Jürgen Habermas has a rather similar concept of rationality as Rescher (Habermas 1992,15):

In contexts of communicative action, we call someone rational not only if he is able to put forward an assertion and, when criticised, to provide grounds for it by pointing to appropriate evidence, but also if he is following an established norm and is able, when criticised, to justify his action by explicating the given situation in the light of le-

<sup>6</sup> Airaksinen and Kaalikoski (1997, 329) have recently discussed the differences between the concepts "rationality" and "reasonability". They suggest that the action of a human being is considered to be rational if in a situation she or he makes a choice based on her preference order. Based on the analysis of Georg v. Wright (1963), they suggest a distinction between "only rational" and "reasonable". They consider that reasonable is a broader concept than rational: rational behavior is based on a given preference order, reasonable behavior is also based on critical analysis of the motives behind preference orders. I use the concept "reasonability" in a very similar sense as March and Simon (1958, 138) have used the concept "bounded rationality".

gitimate expectations. We even call someone rational if he makes known a desire or an intention, expresses a feeling or a mood, shares a secret, confesses a deed, etc., and is then able to reassure critics in regard to revealed experience by drawing practical consequences from it and behaving consistently thereafter.

According to Habermas arguments based on norms are rational (or reasonable), if the community which accepts the norms can shape the future object and *behaves consistently*. The explication of legitimate expectations can afford *learning*, which may change the decisions concerning the future (Habermas 1992, 18):

In virtue of their criticizability, rational expressions also admit of improvement; we can correct failed attempts if we can successfully identify our mistakes. The concept of *grounding* is interwoven with that of *learning*. Argumentation plays an important role in learning processes as well. Thus we call a person rational who, in the cognitive-instrumental sphere, expresses reasonable opinions and acts efficiently; but this rationality remains accidental if it is not coupled with the ability to learn from mistakes, from the refutation of hypotheses and from the failure of interventions.

How can we solve the dilemma of the objective and subjective determinants of future? Is there any way at the same time to accept an objective reality in the future and the possibility that people or other beings can change the future with their decisions? Like Habermas, I consider that the answer to this question can be found in learning processes

## 1.4 Dual Description of the Reality in the General Theory of Consistency

The general theory of consistency (GTC) gives an answer to the dilemma of objective and subjective determinants of the future (Kuusi 1974).<sup>7</sup> The main postulates of GTC and their motivations (as footnotes) are given in the Appendix 1.

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<sup>7</sup> Though different concepts and points of views are used in the GTC than in the epistemic theory of de Jouvenel (1967) many features of the theories are closely related. My concept of "interest" functions nearly in the same role as "project" in the theory of de Jouvenel. De Jouvenel discusses the role of criteria of sameness in a way very similar way to mine in the case of the not-learning being. My concept "genuine learning being" has rather the same role as the "actor" of de Jouvenel. Though the book of de Jouvenel contains no references to learning, some examples used by him clearly refer to the role of learning. An important difference between theories concerns the role of consistency. Consistency and learning are not even mentioned in the index of the book of de Jouvenel. Because I highly appreciate the work of de Jouvenel and his ideas has been an important starting point for present practice in technology foresight, I often refer to his text in my short presentation on the GTC.

The answer of the GTC is based on a dual description of the reality using two types of beings: learning beings and not-learning beings or beings, which are not able to learn. The not-learning beings form the objective reality in Niiniluoto's sense. Because not-learning beings cannot change their behaviour, the truths concerning them are the same now and in the future. Neither a researcher nor any other being can change their behaviour. The future is, however, partly indeterminate because there are also learning beings. Their behaviour dispositions may be different now and in the future.

Different assumptions concerning the role of learning and not-learning beings in reality are possible. A philosophical realist or a correspondence theorist may try to interpret that the whole reality consists of not-learning beings. For example people consist of not-learning atoms and at least in principle the behaviour of people should be possible to be interpreted as an interaction of these not-learning beings. There is, however, at least one genuine learning being: the Cartesian Ego ( "Cogito ergo sum" - I exist, because I think or learn) (c.f. Kuusi 1974, 102).

What kinds of truths do not change in the future? In natural sciences, the basic feature of a scientific discovery is that every scientist who repeats a scientific experiment, obtains the same results or makes the same discovery. This stability is connected with *three groups of criteria of sameness*:

- the object of the experiment (for example a piece of iron) is the same as in the earlier experiment
- the object of the experiment is in the same situation, where the discovery was made (for example the temperature of the piece of iron is the same)
- the object is treated in the same way as in the earlier experiment.

One can conclude that the stabile or invariant elements in scientific experiments are the criteria of sameness, which determine the behaviour of the object. There are, however, sometimes many possible groups of criteria of sameness which may produce the invariance. Thomas Kuhn (1970, 192-194) has stressed the crucial role of the criteria of sameness in the learning of different paradigms. To a large extent, the criteria of sameness of a paradigm are learned through shared exemplars or experiments:

...when I speak of acquiring from exemplars the ability to recognise a given situation as like some and unlike others, that one has seen before ... I am claiming that the explication will not ... answer the question, "Similar with respect to what?" That question is a request for a rule, in this case, for the criteria by which particular situations are grouped into similarity sets, and I am arguing that the temptation to seek criteria (or at least a full set) should be resisted in this case...

If two people stand at the same place and gaze in the same direction ... they receive closely similar stimuli... But people do not see stimuli; our knowledge of them is highly theoretical and abstract. Instead they have sensations, and we have no compulsion to suppose that the sensations of the two viewers are the same... our world is populated in the first instance not by stimuli but by the object of our sensations, and these need not be the same, individual to individual or group to group...

One of the fundamental techniques by which the members of a group, whether an entire culture or a specialists' sub-community within it, learn to see the same things when confronted with the same stimuli is by shown examples of situations that their predecessors in the group have already learned to see as like each other and as different from other sorts of situations.

So according to Kuhn (1970) people learn common criteria of sameness through exemplars. But what is the connection between these criteria of sameness and the real objects? *One can interpret that in addition to the experimenting scientist, the object (a not-learning being) also has the criteria of sameness, which determine its behaviour and which it cannot change.* Invariant criteria of sameness do not require that some present visible property of the not-learning being remains invariant (compare Nagel 1979,149). On the other hand, it is useful to constitute the not-learning beings or the object of studies so that as many of the being's prominent features as possible remain invariant. Eino Kaila is a philosopher who has used the concept of "invariance"<sup>8</sup> in essentially the same way as I have. In a study originally published in German 1941 and in English in 1979, Kaila outlines the concept of "invariance" in the following way (Kaila 1979,150):

We use the term 'invariance' as a collective name for any kind of similarity, sameness, uniformity, lawfulness, constancy, analogy, structural identity (isomorphism). There is, then always a *similarity* - in the broadest sense of the term - between different domains of experience. But we cannot employ the term 'similarity' here, for it tends to lead the imagination on the wrong track insofar as, when speaking of 'similarities', we primarily think of "lower-level similarities", and less of conceptual higher-level similarities...

And further (Kaila 1979,151):

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<sup>8</sup> As was mentioned above Godet (1994) defines an *invariant* as a phenomenon assumed to be permanent up to the horizon studied. From the point of view of the GTC a phenomenon remains invariant (or is an invariant), because it is based on (at least transient) invariant criteria of sameness or *invariances* of relevant beings.

We shall show that "physico-scientific reality" (as to its content) consists in nothing other than the system of higher invariances of the everyday physical world and thus (in the last analysis) 'immediate experience'. We shall demonstrate how this aim, this search for a representation of experience in which its invariance becomes maximal, determines the formation of concepts and theories in physics.

Kaila connects his idea of invariance to the 'economy of thought' emphasised by the physicist Ernst Mach. According to Mach, science "may be regarded as a minimal problem, consisting of the most complete possible presentation of facts with the least possible expenditure of thought" (Mach 1913). An highly important point which closely connects Kaila with my general theory of consistency is the following one (Kaila 1979,154):

If the task is only to represent a fixed and delimited stock of knowledge, the two principles [Mach's principle of economy of thought and the principle of invariance] coincide; but even the attempt to discover the higher invariances possibly contained in this stock of knowledge leads, if it is successful, to generalizations and thus transgressions of this stock of knowledge. To this extent science is not a minimum problem but a maximum problem. It is not a 'parsimonious economy' but a bold adventure, not so much unperturbed enjoyment of the 'stable worldpicture' as a fight against perpetual shocks to which the theoretical mind exposes itself by its generalizations.

Using the concepts of the general theory of consistency, Kaila is speaking about a kind of "translation problem". We have a physical object with its behavioural language of "higher invariances" (criteria of sameness)<sup>9</sup> and we have the observer with her<sup>10</sup> own language. A connection between these two languages is built upon observations or measurements.<sup>11</sup> The point of the translation is not only to explain as simply as possible the past measurements but to anticipate the future measurements (or generalizations) based as far as possible on true invariances (or real criteria of sameness). If the measurements or generalizations produce contradictory results concerning the not-learning being, the observer has to change her

<sup>9</sup> According to Kaila 1979, 228: "The 'essence' of a thing consists of the invariances of this thing."

<sup>10</sup> As I already mentioned, I assume that the learning being or the actor is "she". "She" is so the representative of the both sexes, though I in the connections where the sex matters might use "she" or "he".

<sup>11</sup> A discussion concerning the nature of physical measurements has a central position in the reasoning of Kaila. He criticises Mach's conception of measurement according to which the assignment of numerical values in measurements is only a matter of convenience. According to Kaila (1979,188) the conventionalist theory of measurement is incapable of specifying where in physics the borderline runs between convention and experience. Only such a property can be measured with respect to which there exist lawful relationships of a definite kind (an invariance - my addition), where then the assignment of numerical values is done in such a way that these lawful relationships find expressions in the relations of numerical values (Kaila 1979,192).

translation. A new idea of the General theory consistency is that if contradictory measurements are made concerning a learning being, there are other options: the observed learning being can change her criteria of sameness. Actually the measurement can have a role of "informing" the learning being.

If a researcher succeeds in finding the right criteria (the truth about them), he or she can predict the behaviour of a not-learning object. The right predictions are a necessary condition to the equality of the criteria of sameness between the researcher and the object. It is not, however, a sufficient condition, because the difference in the criteria of sameness may appear in a subsequent wrong prediction concerning the behaviour of the object. De Jouvenel (1967, 85) described the activity of a scientist (or of everybody) seeking the invariant criteria of sameness of not-learning beings:

Identical initial conditions lead to identical results. This is a fundamental postulate of our thought, and no doubt corresponds to what used to be called an innate idea. Our ways of proceeding depend on it: we reproduce the same initial conditions when we wish to obtain the same result. All our confident predictions also depend on it: the result will be the same as before, because the initial conditions are the same as before. But even in nature, and a fortiori in human affairs, the "same as before" is but an approximation, an impression of similarity, a subjective judgement... the points of similarity that strike and convince us are not necessarily the ones that are relevant to the production of the expected result... Or the similarities may be relevant, but a difference which in our eyes is insignificant may inhibit the result we have assumed.

On the other hand, *in the case of a learning being, a wrong prediction does not necessarily tell, that a researcher was earlier wrong concerning the criteria of sameness of the being. The learning being may have changed her criteria of sameness. The basic criterion for the change is an experience of contradiction or inconsistency*: an inconsistency between results of an action and the interests of the being or an inconsistency between anticipated and actual results of the action. If the being has a suitable memory, it can store these types of experiences in the form of changed criteria of sameness. De Jouvenel (1967, 95) is again a good source for illustrating my point, though he did not explicitly speak about learning:

Let us consider ... the forecasting of cigarette consumption in the United States. Before (the learning of! author's addition) the correlation between cigarette smoking and lung cancer had been asserted by researchers, the forecaster obviously could not take into account the future impact of a (learned!) still-unknown assertion... A new (learned!) cause has intervened.



Using the concepts of the GTC, the American people learned that the generally accepted criterion of sameness that smoking is a harmless activity, did not work. They changed this criterion of sameness and also their behaviour.

It is interesting to compare the epistemological standpoint of the GTC to the standpoint of Charles Peirce. As was earlier mentioned, Peirce proposed a scientific method where beliefs should be determined by nothing human, but by some external permanency (Peirce, 1931-35, 5.384). Peirce begins this chapter concerning the methods of fixing belief with a rhetoric question:

...why should we not attain the desired end, by taking as answer to a question any we may fancy, and constantly reiterating it to ourselves, dwelling on all which may conclude to that belief, and learning to turn with contempt and hatred from anything that might disturb it? This simple and direct method is really pursued by many men (Peirce, 1931-35, 5.377).

The GTC does *not* recommend this type of stubbornness to learning beings. We only have to accept the stubbornness of not-learning beings. In other words: we as learning beings have to change our minds because not-learning beings cannot do that.

The following features define a learning being:

- The being can change its behaviour as the result of its experiences.
- The being has interests, which direct its behaviour.
- The being has an active memory, where its experiences are stored.

If any of these requirements is not met, the result is that the behaviour of the being is possible to predict without references to learning and the being can be classified as not-learning beings. *A practical limit between the two types of beings could be the possibility to predict the behaviour of the being so that the being cannot nullify the prediction by changing its behaviour.*

It is of course also possible to find stable elements in the behaviour of learning beings. Because the learning can change these invariances - patterns of behaviour, traditions, expressed preferences, images of the future - I call them *transient invariances* in comparison with the (*permanent*) *invariances* of not-learning beings. The concept of reliability is a common way to describe the stability of a transient invariance.

The genuine interests of a learning being in a way resemble the permanently invariant criteria of sameness of not-learning beings. In the GTC, the genuine interest of a being is characterised by the invariant positive direction ("more of that

aspired by the genuine interest is always better, if the fulfillment level of other genuine interests is given") (Kuusi 1974). A learning being does not typically know her genuine interests, but she learns to know them step by step through her experiences if she has a feasible and active memory. In principle, it is possible that an expert (for example a physician) knows better some genuine interests of a person than herself, though only the person (or some other learning being) has a direct access to her experiences of repentance or frustration.

## 1.5 Capacity and Capability Limits

Capacity and capability limits are concepts which characterise the possibilities of learning. Stafford Beer (1973) referred with the concept of capacity limit to the maximal production possibility of a single machine or of a production unit. By the concept of capability, he meant the real production possibilities of a production unit, taking into account its connections to other parts of the production system for example to suppliers and to marketing channels.

The roots of the idea of the capacity and capability limits lay in the general resource view. According to it for example a firm is seen as a learning being using its resources. Raimo Inkiäinen (1994) saw that the roots of this view in business studies can be traced to Penrose (1959), who stated that "the firm is essentially a pool of resources the utilisation of which is organised in an administrative framework".

The concepts of the capacity and the capability have been tools in a major stream of strategic management research that tries to bridge the gap between organisational behaviour and competitive strategy (Inkiäinen 1994, 42, Barney 1991). The two concepts have been used in different ways. Grant (1991) differentiates between resources which are inputs in the production process, and capabilities which are teams of resources to perform a certain task. Teece & al (1990) provide the following business-specific definition of a capability (Inkiäinen 1994, 44):

... a set of differentiated skills, complementary assets and routines that provide the basis for a firm's competitive capacities and sustainable advantage in a particular business.

Many researchers have connected the concept of capability to the skills of a firm to combine resources. In some recent studies researches have not made a clear distinction between the capacities and capabilities. This has resulted in conceptual difficulties. Difficulties have been connected especially to the use of the concept "human capital resources". For example Inkiäinen (1994), has applied the classification of Barney (1991) of a firm's resources to physical capital resources, human capital resources, and organisational capital resources.

The definitions of Beer (1973) of the capacity and capability limits have been the starting points for the definition of these concepts in GTC. The *capacity limits* (and resources) characterise the capacity of an actor to perform certain actions (to use resources) whenever he chooses. What are the results of these actions and how a learning being is satisfied with these results depend on the *capability limits* of the being. These limits depend on interests, on the environment, where the being tries to promote its interests and on the abilities of the being to store actively experiences. An action theory based on these ideas is given by Kuusi and Keloharju (1985). Basic features of this action theory are described in Appendix 1. The features are presented in a footnote of the postulate 4 of the GTC.

Narrow capacity limits hinder a being changing its behaviour as the result of learning. The behaviour of a being may be predictable and unconnected with its interests, if the being cannot change its behaviour or if the future dominates - using the concepts of de Jouvenel. A disabled cannot save herself from a fire, because this is not within her capacity limits. In this situation the disabled behaves like a not-learning being. The example of de Jouvenel (1967, 52) was:

I foresee that I will be soaked by rain, but I can contradict (or master) this prediction simply by putting on a raincoat. Here "it will rain" describes a dominating future over which I have no power.

A simple thermostat is a being, which cannot change its capability limits or its limits of its consistent behaviour. This is the reason to classify it as a not-learning being, though it has an "interest" in keeping temperature within some limits and it has a capacity to start an action, that contributes to fulfillment of the target. A simple thermostat cannot change its criteria of sameness concerning the situations, because it cannot repent its behaviour and change its criteria of sameness.

A computer, which is programmed to do some before determined tasks, is also a being, which cannot change its criteria of sameness. It is an example of a not-learning being, which has a memory and action capacities but does not have interests. A computer can change its criteria of sameness only if somebody changes its software to promote her interests.

We can give an interpretation of the *real capability limits* using the concept of the rational behavior or the best possible behaviour. Real capability limits are boundaries of rational behaviour. Within the real capability limits are all rational choices based on perfect information.. It is reasonable to suppose that within the real capability limits of an actor are typically more choices than only one. From the point of view of the actor these different alternatives of rational behavior are similar in that sense that the actor has not to repent, if she chooses any of them. From the point of view of other actors the choices might, however, be very dif-

ferent. This assumption has an interesting implication: *The rational future is not determinate. There are many rational futures.*

The choices of actors are not based on real but on *perceived capability limits*. If real and perceived capability limits unite, an actor behaves rationally. This means that further learning could not change the behaviour of the actor. *In reality it is only possible to infer that an actor is reasonable or rational in the limits of the actor's perceptions.*<sup>12</sup> *Nobody cannot know, whether an actor's choices are rational.*<sup>13</sup>

Real capability limits refer to that concept of rationality, which Habermas vaguely says to "transcend spatio-temporal and social limitations" (Habermas 1995, 31). They are independent of the subjective evaluations of learning beings and are in this respect objective or "true" also in the meaning of Niiniluoto and Peirce.

## 1.6 Cognitive Maps of Learning Beings

A being capable of actions in the sense of de Jouvenel (1967,26) is clearly a learning being. The concepts "the genuine learning being" and "the actor" are practically identical and I have used both of them. It is interesting that de Jouvenel did not recognise the special learning capacity as the most important distinctive mark of the genuine actor. He did not see the epistemic importance of the fact that behind every relevant future image or project is a learning process which has started not at the birth of an individual, but actually in the form of DNA- or RNA-memories at the time when the evolutionary development of living organisms began.

People and intelligent animals are examples of genuine learning beings as are their organisations. In the future, an important group of learning beings will probably be neural computers, the behaviour of which is ruled by programmed interests and which can make action decisions independently. Even now it may be plausible to interpret the computers and even written documents to be organic parts of learning organisations. Analogously to not-learning beings, it is reason-

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<sup>12</sup> The rationality assumption belongs to the standard theory of economics. Actually this assumption does not suggest that people are in reality rational. The assumption suggests that if people behave rationally, their properties (e.g. preferences) should be those inferred e.g. from econometric models. In reality they might be or might be not. Like any actor also an economist can only look at perceived capability limits. The economist might consider that an actor behaves in a reasonable way, if the actor's perceived capability limits - related e.g. to the actor's measured preferences - are those transient invariances inferred from econometric models.

<sup>13</sup> This type of knowledge contradicts the definition of the actor given in the postulate 5 of the GTC. It would be possible to predict the behavior of the actor without further learning related information.

able to constitute learning beings so that their interests, capacities and capabilities can be discerned.

An advantage of the general theory of consistency is that very concrete interpretations to its basic concepts can be given. The concepts of the GTC are suitable to describe the physical learning processes in animal neural systems and the evolutionary learning of the biosphere as well as learning processes of organisations.

A basic interest in evolutionary learning is survival or replication (e.g. Pantzar 1991). The relevant experiences are collected beside the neural networks to the DNA- or RNA-memories of organisms. It is important to realize that DNA or RNA molecules are active memories of every living cell. It is commonly believed that these memories can change only when two genetically different organisms have a common descendant. DNA-memories in single cells can, however, change essentially for example when viruses connect themselves to DNA molecules or when radiation changes the order of bases or nucleotides, resulting sometimes in uncontrolled fission of cells ( the formation of cancer cells).

The changes in DNA molecules as well as in neural networks (for example deaths of nerve cells and new or stronger/weaker synaptic connections) are necessary but not sufficient conditions for changes in the criteria of sameness. An active memory requires both a passive registration (coding) of experiences and an active (decoding) mechanism for information retrieval. The changes in a functional memory are connected to the unanticipated changes in the environment of an organism, which are relevant to the targets of the organism and result in the proper behaviour of the organism. In practice, concrete memories (for example DNA-memories) often poorly correspond to the features of an ideal memory.

A memory is a system of more or less interconnected parts. In some decisions, only very limited parts of the system are activated as in the case of reflexes. Some other decisions are results of the activation of large parts of the system. We may interpret that behind every decision *mental or cognitive maps (or a map)* are stored in those areas of memory, which have been activated in decision making situations (compare for example Laztlo et. al. 1993 p. xii). Only those criteria of sameness which belong to the used cognitive maps have impacts on the decision. They are thought to be *relevant* in decision-making.

Capability limits can be interpreted to be properties of an ideal cognitive map including those criteria of sameness which are relevant in a decision-making situation. The real cognitive maps are far from the ideal ones. They define the perceived capability limits and the decisions of the learning beings are based on them. The results of the decisions depend on the real capacity limit of decision-makers, though the decisions made are based on perceived capacity limits.

Learning beings try to realize the choices belonging to their perceived capability limits, but are often incapable of realizing the anticipated results.

The experiences of inconsistencies change the cognitive map of a learning being. Kuusi (1974) has described the changes with inversely unequivocal negations, which may have their counterparts in neural networks (for example negation in a binary dimension, negation concerning the relevance and negation concerning the antagonism; they are discussed briefly in Appendix 1).

## **1.7 Learning Organisations as Special Cases of Learning Beings**

Levitt and March (1988, 319-320) consider in their literature review that organisational learning is routine-based, history dependent and target-oriented. Organisations are seen as learning by encoding inferences from history into routines. They can be seen as cognitive maps that guide behaviour. The generic term "routines" includes the forms, rules, procedures, conventions, strategies and technologies around which organisations are constructed and through which they operate. They also include the structure of beliefs, frameworks, paradigms, codes, cultures and knowledge that elaborate the formal routines. Routines are independent of the individual actors who execute them and are capable of surviving considerable turnover in individual actors.

Routines are recorded in a collective memory that is often coherent but is sometimes jumbled, that often endures but is sometimes lost (Levitt and March 1988). The collective memory has many concrete places: the brains of the persons in the organisation or persons communicating with it, written documents, computer files and even the layout of the office of the organisation. Routines change as a result of experience within a community of other learning organisations. These changes depend on interpretations of history, particularly on the evaluation of outcomes in terms of targets.

Routines in the wide meaning of Levitt and March (1988) are the base of legitimate expectations about the future in an organisation. Using the terminology of Habermas (1984), making a decision based on organisation's routines is rational in that organisation. In the terminology of the GTC, a decision based on an organisation's routines is a solution which the organisation believes to be within its capability limits or a solution which the organisation does not expect to repent in the future.

The independent role of an organisation as a learning being is stressed by the fact that what may be reasonable to the organisation may be irrational to its individual members. A form of organisational learning may even be the restrictions on the individual learning. According to Levinthal and March (1993,97), organisations

use two major mechanisms to facilitate learning from experience. The first is simplification. Learning processes (or routines) seek to simplify experience, to minimise interactions and restrict effects to the spatial and temporal neighbourhood of actions. The second mechanism is specialisation. Routines tend to focus attention and narrow competence.

In technology foresight organisational learning and routines have a crucial role. I will (in Chapter 3) call experts in organisational learning or in relevant routines "experts in processual arguments".

## **1.8 The GTC Paradigm of Futures Studies**

### **1.8.1 Basic Orientation of Futures Studies**

Thomas Kuhn have presented four criteria for a science, which has proceeded from a pre-paradigmatic phase to a paradigmatic phase (Kuhn 1970b, 245-246):

1. The paradigm provides concrete predictions concerning some phenomena of nature which can clearly be proved to be right or wrong (an interpretation of the Karl Popper's demarcation criterion).
2. The paradigm provides consistently successful predictions for a specific group of phenomena of nature.
3. The methods of prediction have to be based on a theory, which gives a kind of metaphysical justification to predictions, which explains partial successes and suggests means to improve the predictions concerning both the accuracy of prediction and the amount of predicted phenomena.
4. The use of suggested methods should be a demanding and challenging job, which requires gifts and involvement.

How can futures research obtain features of a paradigmatic science? Different researchers have suggested different features for the paradigm (or for the pre-paradigm) of futures research. Most of futures researchers share the viewpoints of Wendell Bell and Theodore Gordon, which are in line with the epistemology of de Jouvenel (1967) and Godet (1994). Bell has suggested that the right orientation to the futures research is

An orientation toward conscious decision-making and social action aimed at adapting to or controlling the future (Bell 1987, Mannermaa 1991).

According to Theodore Gordon (1989), the paradigm of futures research supposes that:

The future is not preordained and can be shaped by the actions of individuals, institutions and natural forces. This first paradigm suggests, that actions change the future. There is a future without action, and a different one with it. Thus futures research and predestination are, at least on the surface, antithetical.

The implicit epistemic assumptions of most futurologists can be found in the scenarios made by them. The original definition of Herman Kahn and Anthony Wiener (1967,6) of the concept of scenario was as follows:

Scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points. They answer two kinds of questions: (1) Precisely how might some hypothetical situation come about, step by step? and (2) What alternatives exist, for each actor, at each step, for preventing, diverting, or facilitating the process?

The definition gives practical content to the statement of Gordon. There are scenarios without action, and different ones with it.

### *Values and the GTC Paradigm of Future Studies*

An important aspect of the paradigm of futures studies concerns values. For example Wendell Bell (1997) has focused the second volume of his *Foundations of Futures studies* to this problem. He discusses extensively the role of utopian writers (for example Thomas More, Daniel Defoe, Jean Jacques Rousseau and Karl Marx), religious traditions and legal traditions based on "collective judgments of groups" in the formulation and interpretation of values.

We may with standard methods of science produce transient invariances concerning (Bell 1997 vol. 1, 188-189):

1. Present images of the future and expectations for the future that people hold, that is their conceptions of the possible.
2. People's belief about the most likely future, that is their subjective probabilities concerning the chances of particular futures occurring.
3. The goals, values and attitudes people hold; the preferences they use to evaluate alternative images of the future, that is, peoples hopes and fears for the future.
4. Present intentions to act.
5. Obligations and commitments that people have to others.

The problem is how to evaluate the rationality or reasonability of all presented images of future, goals, intentions and hopes. Will the transient invariances also last in the future or should they last? A "mainstream" idea of scientists concern-



ing values has been that scientists cannot tell how things should be, but only how they are ("Hume's guillotine").

Many prominent future researchers have, however, considered that reasonable argumentation concerning values is possible. For example Pentti Malaska has seen value rationality as an important feature of future research (Malaska 1993):

Future research is a value rational science. It differs from normal sciences in the way it handles values and value judgements. They are not excluded from scientific treatment and they are not assumed to be general and common to all people. They are not assumed to be determined somewhere outside the topic of future research from where values are found in a way given.

Roy Amara has specified the paradigmatic features of the future research in the following three theses (Amara 1981, Mannermaa 1991):

1. The future is unpredictable. From this follows, that conceptions of future should be based on the description of possible paths of development. "What is possible?"
2. The future is not predetermined. From this follows, that the possible alternatives of future and paths to them have to be studied carefully: "What is probable"?
3. The choices have impacts on the future. From this follows that choices should be made between the alternatives and the realization of the paths to the selected alternatives should be studied: "What is desirable?"

A similar type of definition was given by Bell (1997 I, 73):

The purposes of future studies are to discover or invent, examine and evaluate, and propose possible, probable and preferable futures.

Is it possible to rationally discuss future oriented values from the epistemic starting points of the GTC? Let us start the discussion from the starting points proposed by de Jouvenel (1967). He considered that ends and means are interconnected in values having impacts on behaviour. Values are represented as images of the future, constructs (e.g. plans) or interests formed in our minds. These constructs "represent" facts in a subjective manner, however.

The fact that values are based on both ends and means has important consequences for the reasonable discussion about values. Based mostly on the discus-

sion of Keekok Lee (1985), Wendell Bell (1997 II, 82-98) formulates three possible options for reasonable argumentation concerning values:

- commitment-deductibility model,
- means-ends model,
- epistemic implication model.

In the commitment-deductibility model, a lower-order moral assertion can be justified by a higher-order assertion, and the latter by others and so on. Thus there is deductibility through logical consistency. Ultimately the highest-order assertion, and thus the entire system of justification itself, rests on an act of faith or will. An assertion rests on "sincere commitment" to the highest-order principle.

The commitment deductibility model describes rather well many actual argumentation processes concerning values. Many religions give first principles for human actions, which priests interpret. The systems of laws are also very much based on the same idea. Jurists and civil servants deduce from written laws the right actions from the point of view of "public will". The present management decisions are evaluated in terms of their compatibility with the organisation's long range ethical commitments as expressed in its mission statement. More generally, common action of different actors for example a common developing process of a technology is typically based on commonly accepted rules. The success of common projects is to a large extent based on the commitment of different actors to the "first principles".

The problem of the model is that it provides no way to rationally evaluate the relevancy of the first principles. Do they cover all relevant aspects of actions? Do they give right relevancy values to different actions? The second model discussed by Bell - the means-ends model - implies the same problem.

Ilkka Niiniluoto is a sophisticated representative of the means-ends model. Niiniluoto (1993) has sought a role for future research as a planning science. Niiniluoto has defined design or planning as a systematic endeavour where precepts are sought to achieve given targets with optimal use of resources. The target of a plan can be a material artifact (for example consumer commodity, machine, a work of art, or a building), a social organisation (for example a society or a political party) or an action (for example an action decision).

Niiniluoto has suggested that the difference between planning sciences and descriptive sciences is that the knowledge produced by planning sciences is not descriptive but instrumental, providing information concerning the connections between targets and means. The findings of planning sciences can be given in the form of technical norms or practical syllogisms (v.Wright 1971):

(N) If you want target A and you believe that you are in situation B, you have to do X

Unlike unconditional norms (You have to do X !), technical norms are according to Niiniluoto sentences with truth values: Norm N is true, if the doing of X is a necessary condition of A in situation B. If X is only one possibility to promote A, the norm can be given in a weaker form "it is advantageous for you to do X".

For example econometric planning models are typically based on empirically supported technical norms. The empirical estimations of relations between variables based on regression analysis of the past data are typically clearly distinguished from decision parameters in econometric planning models. The numerical values of decision parameters describe the values and targets of decision-makers who use an econometric model.

Although the seeking of true technical norms is a scientifically plausible activity, the idea that it is the only possible way to do scientific future research, greatly limits the scope of the scientific future research. In real planning activities, an expert can often predict a change of mind of a decision maker. A decision maker's old target values might contradict her new target values. This is an activity which de Jouvenel (1967, 55) called the making of tertiary forecasts. Is it really so that there is no possibility to look rationally at this type of expertise?

The third model discussed by Bell (1997) is Keekok Lee's "Epistemic Implication Model". The idea in Lee's model (Lee 1985) is that her "epistemic implication" is based on contingent knowledge obtained under empirical conditions. Lee places the knowledge squarely within Popper's fallibilism, which she applies to the grounds supporting value assertions and which she enriches by requiring criteria of relevance.

Lee's epistemic implication model does not argue that one can go from "is" to "ought"; it assumes that prescriptive statements contain or rest upon some descriptive contents that can be tested, that is either falsified or confirmed by surviving serious efforts to falsify them. Lee (1985, 105) points out that such logic has been around for some time in moral philosophy. For example, she shows that the Kantian dictum "ought" implies "can" is similar. You are not morally obligated to do what you cannot do. Lee, however, goes further: she makes the descriptive elements or grounds of any perspective statements subject to test.

The idea is to subject the descriptive elements of value assertions to a series of criteria, including empirical testing. By implication we can reach a tentative judgement about the validity of value assertions. She gives five criteria to be met in making such a test:

### 1. *Serious Evidence*

The evidence required to support or falsify an assertion must not merely refer to the attitude of the speakers towards their assertion or their psychological state of mind regarding it. Thus, mere individual preferences, desires, or wants are not admitted as serious evidence. Instead, serious evidence requires that there is some public external features of the situation referred to in the assertion. It includes only assertions that can be denied or confirmed by independent observers, by some kind of objective or intersubjective process. Lee's example is the assertion: People ought not to smoke tobacco. It is supported by the (serious) evidence: Because to do so increases their chances of dying of lung cancer.

### 2. *Referentially Relevant Evidence*

"Referentially relevant" means that the assertion and the reasons for it must be about the same thing. They must share a common term, that is, the subject term (Lee 1985, 87). To say that "this young woman fainted" as evidence for "this young woman is ill" is referentially relevant. Both the evidence and the conclusion concern the young woman. The assertion "because  $2+2 = 4$ " does not meet the criterion of referential relevance. The value assertion and the evidence have to deal, at the very least, with the same class of objects, people or events.

### 3. *Causally Relevant Evidence*

The evidence cited to test a moral assertion must bear the assertion in some causal way like in the means-ends model. Human understanding of causal relationships in the world is, however, incomplete. Evidence might be referentially relevant, but could still fail the test of causal relevance. For example, to say "oxygen is colourless" as evidence for "oxygen is necessary for combustion" fails because there is no causal connection between the colour of oxygen and its combustibility.

### 4. *Causal Independence*

Relevant serious evidence must be "causally independent" of the conclusion (Lee 1985, 99). The evidence is not acceptable if it is produced by the conclusion itself, as in a self-fulfilling prophecy. The evidence, in other words, must have occurred earlier in time than the conclusion and it must not have been a result of the conclusion. This is for example valid in the case of smoking and cancer. A contrary case of Bell is a white supremacist assertion in the period of plantation slavery in the Americas: "Africans ought to be treated as socially inferior" the evidence being that "Africans in fact are socially inferior". Let us grant that it is causally relevant, that being socially inferior might be a cause of being treated as socially inferior, although this is shaky and can be challenged. This evidence according to Lee fails because the value judgement contained in the original assertion may have caused the evidence. The evidence is inadmissible in support of the assertion because it is not causally independent of it.

### 5. Empirical Test

Finally, there is the requirement to put the evidence to an empirical test, to assess whether it is true or false. If the evidence meets the above four criteria, the evidence, if true, would serve to support the assertion, while if false, would serve to refute it. For example the hypothesis that smoking causes lung cancer has survived many efforts to falsify it.

From the perspective of the GTC Keekok Lee's model is clearly the most interesting of the three models. In practice the model includes the second model. The acceptance of a value assertion is related to means of its realization or truthful technical norms. Like de Jouvenel (1967), Lee's model considers value statements as interconnected networks of ends and means. The GTC also supposes that every prescriptive statement refers to the perceived capability limits or interests of learning beings or actors. The capability limits or the limits of "not regretted behaviour" classify actions or plans as feasible and not-feasible. The realizing of an interest is an attempt to realize a feasible plan or an "image" of the future. Like ethical statements in Lee's theory the concepts "capability limits" and "interests" include both descriptive and prescriptive dimensions.<sup>14</sup> *The ends and means of interests are so interrelated that it is possible to evaluate the validity of every statement concerning real capability limits or genuine interests based on some descriptive dimensions.* The four criteria of Lee can be used in the evaluation of every statement concerning real capability limits or genuine interests of actors.

The fourth criterion is especially interesting from the perspective of the GTC. It can be seen from the perspective of connections between capacity and capability limits. Let us once more look at the white supremacist assertion in the period of plantation slavery in the Americas: "Africans ought to be treated as socially inferior" the evidence being that "Africans in fact are socially inferior". The statement "Africans in fact are socially inferior" refers to the present capacity limits of Africans. If these capacity limits cannot change (which is not true) this fact has implications concerning future capability limits (limits of not-regretted behaviour): Africans ought to be treated as socially inferior. The reasoning contradicts with one type of reasonability, which will be discussed later: option reasonability. It does not take into account relevant possible options.

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<sup>14</sup> The GTC also points to the similarity of ethical standards and invariances of not-learning beings. Ethical standards refer to suggestions concerning the real capability limits of learning beings or actors. We can give the following interpretation of a suggestion of ethical standards: if you follow the basic ethical standards, you will not regret your choices. Because real capability limits are as invariant as the criteria of sameness of not-learning beings, this points to the similarity of ethical standards and invariances of not-learning beings. Suggested ethical standards can be criticized like suggested invariances of not-learning beings.

Lee and Bell do not discuss a further evaluation criterion which is evident from the point of view of the GTC. Bell discusses a form of this criterion when he discusses future-oriented value statements (Bell 1997 II, 95-101).

Bell considers that most prescriptive statements have at least implicit future orientation. In different ethical theories the future-orientation is more or less evident. This orientation is most evident for consequentialists. For them, judgements of the good on which people base their decision to act rest upon anticipations. According to Bell (1997, 96) also contractarianist, utilitarianist and deontological theories of ethics contain inherent futures orientation. Even a deontologist, whose ethical judgements are based on duties, may add to an ethical judgement a remark 'see that you don't do it again' for example in the correcting the behaviour of a child (Bell 1997 II, 98).

The future orientation of prescriptive statements is based on the similarity of past and future situations. It is highly important to realize that this act of generalization from the past to the future is not a simple or self-evident logical operation. It is based on the criteria of sameness of the actor. The criteria of sameness may change if the actor perceives that her criteria of sameness are contradictory.

The epistemology of GTC is based on the idea that the first principles or moral rules are special types of criteria of sameness. Like other criteria of sameness of an actor, they are based on learning experiences. The learning experiences are not necessarily the learning experiences of the actor but mediated learning experiences of others for example in the form of routines, traditions or religions. Though the criteria of sameness are often or even typically approved without private experience, they are tested based on private actions and privately perceived contradictions.

Though I highly appreciate the idea of intersubjective evidence concerning the reasonability of moral judgements proposed by Keekok Lee and Wendell Bell, I consider that the reasonable evaluation of value judgements can also be based on a further evaluation criterion: *the criterion of non-contradictory criteria of the sameness of an actor*.

Arguments of this type is very common in practical argumentation processes. For example in the discussion concerning abortion, the following argument is based on that criterion:

If abortion is allowed for economic reasons, why not accept abortion based on difficult hereditary diseases?

The problem is, does abortion based on hereditary reasons belong to the similarity group of abortions based on economic reasons. This depends on the ethical

paradigm of the actor. We are actually approaching the commitment deductibility model presented by Lee but without supposing explicit first principles.

Presenting of a threat is a special kind of argument concerning the consistency of the criteria of sameness. The basic function of a threat is to suggest that a threatened actor will regret an action if the actor performs the action. It is suggested that there will be a contradiction between the anticipated results of the action and the realized results.

### **1.8.2 How do the Epistemic Starting Points of GTC Meet the Requirements of a Kuhnian Paradigm?**

How do the epistemic starting points of GTC fulfill Kuhn's conditions for a paradigm presented above? *Firstly*, the GTC provides concrete predictions with truth values in different ways concerning the future behaviour of learning and not-learning beings. One can make concrete predictions about the behaviour of not-learning beings making assumptions about their invariant criteria of sameness. The falsification of these assumptions is possible. But how do we falsify the assumptions concerning the criteria of sameness of learning beings or how to predict the changes of their criteria of sameness? Whenever a learning being has some criteria of sameness, she can have true or false hypotheses concerning them. The problem is the evidence, which could falsify a false hypothesis.

The evidence has to concern the learning processes of the learning being. Learning processes are often non-deterministic. There are often many choices, within the capability limits (the limits of not-regretted behaviour) of learning being. This is another way to express the second point of Amara presented above. One can try empirically to form a conception about the capability limits: one may look at the choices made by the similar type of learning beings in similar situations. Any choice is relevant concerning the perceived capability limits but not concerning the real capability limits. The real capability limits are related on future repentance of choices. Those choices, which the being has not regretted, might belong to real capability limits. We do not know, however, if some further experience of the actor will result in repentance. In the case of learning beings there is a continuous discrepancy between the behaviour based on imperfect knowledge and the ideal reasonable behaviour.

*Secondly*, what may be the regularly successful predictions of the GTC paradigm? In addition to the instrumental predictions of the paradigm suggested by Niiniluoto, the paradigm might provide successful predictions about what a learning being or an actor cannot do, because the action is not within its capacity limits, and what it should not do, because the action does not belong to its capability limits (it will regret that type of behaviour, if it does it).

*Thirdly, the general theory of consistency gives a metaphysical justification to predictions. In summary, futures research based on the GTC paradigm is research on the capacity limits, capability limits and interests of actors and the study of possible futures based on this type of knowledge. In the case of a not-learning being, the activity recommended by the paradigm is the seeking of invariant criteria of sameness.*

In the case of a learning beings, there is always a discrepancy between ideal and perceived capacity limits, capability limits and interests. The discrepancy depends on cognitive maps based on the (concrete) memories of learning beings. The idea of the GTC is that a learning being continuously changes its cognitive map in response to experiences of inconsistency (for example unexpected events).

The basic epistemic standpoint of the GTC is the coherence theory of truth. Niiniluoto's basic critic of the coherence theory ("that a sentence A is compatible with a consistent set X of true sentences, is not sufficient to guarantee the truth of A") does not, however, apply to the GTC. In the GTC truth values do not depend on the relationships between sentences but on the relationships of sentences to the consistent behaviour of a study object (for example a not-learning being). In that sense it is a version of the correspondence theory.

In the study of not-learning beings "the practical coherence hypothesis" is just the same, which de Jouvenel (1967,85) called our innate idea: identical initial conditions lead to identical results. We expect from a not-learning being coherent behaviours in similar situations. If the hypothesis is falsified by inconsistent behaviour of a not-learning being we do not refute our "innate idea", but we consider that we have made false presuppositions concerning the criteria of sameness of the not-learning being.

The situation is much more complicated in the case of learning beings. As Charles Peirce in the above cited paragraph mentioned, some persons believe that they can make things true, if they behave as stubbornly as not-learning beings (Peirce, 1931-35, 5.377). But reasonable learning beings change their criteria of sameness based on new information and results of their actions. There is, however, a special kind of coherence which directs the actions of learning beings. Their action has to be in coherence with their earlier experiences as these are stored in their memories. In principle, if another learning being could realize all experiences in the memory storage, she could anticipate the action possibilities. This is of course only a theoretical possibility and even contradicts the definition of the (genuine) learning being.



## 1.9 Basic Types of Expert Knowledge about Future

One can find four possible types of expertise on the future based on the general theory of consistency (GTC).

- the expertise on the invariant behaviour or invariant criteria of sameness of learning or not-learning beings
- the expertise on the capacity limits of learning beings
- the expertise on the interests of learning beings
- the expertise on the capability limits of learning beings.

The basic types of futures-oriented expertise get different weights in different futures-oriented activities.

The invariant behaviour of not-learning beings means a possibility to make deterministic predictions about the future behaviour of these beings. A weaker form of this type of prediction is a prediction based on the assumption that some learning beings behave as they used to behave. Let us refer to experts in these two types of knowledge with a common name: *(traditional) scientists or experts on invariances*. Natural sciences have tried to find not-learning beings and their empirically supported criteria of sameness ("natural laws") or invariant behaviours. On the other hand, behavioural sciences had tried to find (transient) invariances of learning beings and their empirically supported criteria of sameness, learning possibilities (for example memories), capacity limits, interests and capability limits of behaviour.

An important expert group on the future use of a generic technology comprises those actors, who have a large supply of relevant resources (wide capacity limits) and relevant interests (decisions concerning the generic technology belong to their capability limits). We may call this group *decision-makers or the makers of futures*. A difference between scientists and the developers of technologies in firms has been that the latter are more interested in ways to widen capacity limits to achieve different targets (to promote interests) than to find invariances. The capacity and capability limits of different actors are interconnected. The decision of a powerful decision-maker can move a choice of a less powerful decision maker beyond her capacity or capability limits. A qualified decision-maker knows the limits of her power. Her power to shape futures depends on her expertise on interests and decision routines of other relevant decision makers. No decision maker can change the genuine invariances.

We might suppose that actors themselves are typically (with some exceptions) the best experts of their genuine interests and their present capacity limits, but often not of their capability limits or their future capacity limits. For example the experts, who know the relevant invariances well, often know better than people themselves, which types of resources satisfy the interests expressed by non-

experts. These experts might be the best in the understanding of real capability limits. We may call this third main group of futures experts *synthesizers*. Synthesizers are masters of relevance. Their ability to make good syntheses means that they are able to understand which invariances, capacities and decisions are most important, and they can anticipate the interplay of factors that shape futures.

*Figure 1.1. Three types of experts about futures*

	Types of expertise
Scientists	Knowledge on invariances: - permanent invariances: criteria of sameness of not-learning beings - transient invariances: habits, routines, equilibrium points of learning of actors
Decision-makers	Real and perceived capacity limits; perceived interests and routines; real and perceived capability limits
Synthesizers	Relevant invariances, relevant capacity limits, relevant interests and relevant capability limits

I will illustrate the three basic types of expertise with a building process of business scenarios. Typically, technology Delphi processes are related to scenario processes in firms.

Tarja Meristö has defined a business scenario as a hypothetical view of the future, which holistically and multidimensionally drafts a future action environment for an enterprise and describes a development path from the present to a future (Meristö 1991,45). Meristö has classified the scenarios used in the strategic management of large corporations into mission scenarios, issue scenarios and action scenarios. The proposed phases of the scenario process describe rather well the scenario work in the ten big multinational corporations (Meristö 1991, 107-110).

The purpose of mission scenarios is to help the top management to realize "who we are and where we are". What are the possible worlds for the whole corporation? In these scenarios possible business areas are discussed. Should the firm diversify or concentrate on some key areas?

The idea of issue scenarios is to respond to the question "what are the possible worlds". Issue scenarios serve many units in a corporation and they are usually

made by planning staff at the corporation level, but also using the expertise of business units. The issue scenarios describe the environment of the corporation and they provide frames of reference for action scenarios.

The action scenarios seek answers to questions such as "where can we go and how? where do we decide to go?" Meristö and Pentti Malaska have developed a practical model for making action scenarios. It proceeds in eight phases and it uses mission scenarios and issue scenarios as inputs:

1. The appointment of the working group and setting of its targets. The definition of the strategic task of the business unit.
2. The clarification of the basic beliefs of the business unit.
3. The mapping of the possible changes (the "possible worlds").
4. The clarification of threats and opportunities, strengths and weaknesses.
5. The making of scenarios.
6. The selection of final scenarios.
7. The new definition of the strategic task of the business unit.
8. The final evaluation of the working process.

The crucial features of the action scenario approach of Meristö are as follows (Meristö 1991, vi):

1. Those who are responsible for strategic decisions are also responsible for the action scenario approaches and the whole process to formulate and illustrate the scenarios. This ensures the commitment needed in decision-making and in action.
2. The action scenario approach describes not only the alternatives of the future environment, but also includes the strategy formulation based on those alternatives. This creates flexibility for the strategies.
3. The action scenario approach integrates futures studies with strategic planning and is independent of the planning process used by the company.

What kind of interpretations can be given to the scenario process suggested by Meristö (1991) using the three basic types of expertise?

The main aim of the scenario process is the synthesis of different types of expertise: expertise in permanent or transient invariances and the decision-making expertise. Meristö has crystallised the use of scenarios in a firm in the following way (Meristö 1991, 23, Kite 1981): future research without connections to decision-making is a waste of time and other resources, but without futures research one cannot speak about freedom of decision-making, because the possible alternatives for action are not noticed and one has little freedom of choice.

The synthetic process is clearly visible in the eight phases of action scenarios:

1. A preliminary synthesis (based on mission and issue scenarios) is presented in the form of the strategic task of the business unit.
2. The most important concepts (criteria of sameness) and invariances are presented, on which the preliminary synthesis is based.
3. The relevant future possibilities within the capacity limits of the organisation are discussed.
4. The clarification of capability limits based on perceived invariances ("threats and opportunities") and resources ("strengths and weaknesses").
5. The preliminary futures within the capability limits of the organisation.
6. The final futures within the capability limits of the organisation.
7. The final synthesis in the form of the strategic task of the business unit.

In making different scenarios, different types of expertise are stressed. On the general level, it is reasonable to assume that in making mission scenarios the order of importance of types of expertise is the expertise based on the use of resources (or decision-making expertise), synthetic expertise and expertise in invariances. In the case of issue scenarios, the order may be expertise in invariances, synthetic expertise and expertise based on the use of resources. In making action scenarios, the order may be synthetic expertise, expertise in invariances and expertise based on the use of resources.

## 2. TECHNOLOGICAL PARADIGMS AND THEIR DEVELOPER COMMUNITIES

### 2.1 How to Define a Technology?

Technological development is a special type of human learning. The use of a technology is not based just on things, it also encompasses skills and knowledge, and vice versa. This concerns not only mental skills. A typewriter without a user who can type and read is a useless, heavy piece of material. It would not be a typewriter. A technology is a totality of skills and interconnected technical solutions. A typewriter that has been deconstructed into hammers, springs, keys and bars is no longer a typewriter. And vice versa, it would not make sense to talk about the skill of typing without referring to the thing (Rip 1995,18).

The historian Charles Singer has given the following definition of technology: technology is how things are made and what things are made (Rip 1995,18). Recognizing that a technology must work in a more or less routine-like way, in a more or less recognizable way, it is clear that technology does not only refer to "things" and "skills", but also to the way things and skills are part of the routines of organizations.

There are three "poles" in technical learning processes (Techno-Economic Networks 1991, 29), the interpretations of which in the GTC is given in parentheses<sup>1</sup>:

- the *science pole* (S) or production of "certified" knowledge and embodied skills (expertise in invariances),
- the *technology pole* (T) or development of devices of varying complexity which enlist human and non-human resources to obtain anticipated results or targets on a routine basis ( the widening of capacity limits) and

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<sup>1</sup> The three poles are represented by typical institutions. According to Callon (1992) (cf. Green et al. 1998,6), the scientific pole consists of universities and public or private independent research centers; the technical pole consists of technical labs in firms, co-operative research centres and pilot plants and the market pole contains users, professionals and practitioners.

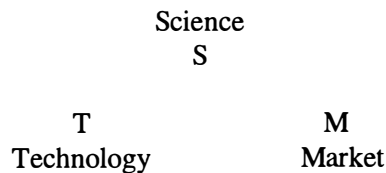
- the *market pole* (M) which structures and organizes demand or seeks relevant targets (interests, perceived and real capacity limits).

The technical learning process can be better analysed if the intermediation activities S T and TM are also discussed :

- the transfer pole ST is the interface between science and technology (the use of invariances in the widening of capacity limits) and

- the development pole TM, which comprises activities in the areas between technology and the market (the widening of goal relevant capacity limits).

In some connections the third interface SM may also be relevant. It means that the science is used in analyzing market demand or relevant targets (the use of invariances connected with capacity limits).



From these starting points we can give a definition of a technology:

A technology means a group of techniques and targets achieved or reasonably believed to be achievable with these techniques based for example on scientific invariances. A technology is based on similar targets or techniques.

I will use the concept "technology" more generally than the concept "technique". The technology includes both the target(s) and means to achieve the target(s). The technique refers only to some way to achieve target(s). This interpretation does not contradict the original use of the concepts "technology" and "technique" (Volti 1992, Autio 1995). The word "technology" is derived from the Greek words "techne" and "logos". The word techne can be interpreted as skill of hand or technique. The word logos means knowledge or science. Thus technology can be viewed as a knowledge of skills or techniques. It is reasonable to suppose that the knowledge of a technique also includes the targets for which the technique can be used.

It is actually unfeasible to study techniques and targets separately because as Bruno Latour (1993, 3) has stressed, the targets and the technologies to attain them are not independent. A technology is a sufficient but not a necessary condi-

tion to attain a target. A technology gives to an actor a capacity to attain a target but the attainment does not necessarily belong to the capability limits of the actor:

"Guns kill people" say those who try to control the free sale of guns. To which the National Rifle Association replies with another slogan "People kill people; not guns"...

With a gun a new goal is possible:

You simply wanted to hurt but now that you have the gun you want to kill ... You are a different person with the gun in your hand (Latour 1993,5)

The importance of the achieved targets of a technique and its efficiency vary. If a technique or products produced by it have positive net economic value we may refer, in analogy with Freeman (1982) to an innovation. Without a realized economic value a new way of achieving a target is just an invention. Kimmo Kuitunen has defined technological innovation as a commercialized idea in any of the following dimensions: products, production processes or work organization at all levels (Kuitunen 1993,22, Whipp and Clark 1986). Oslo Manual (OECD 1997) has outlined guidelines for internationally compatible innovation surveys. According to this manual the minimum requirement for a technological product and process innovation (TTP) is that it is new for a firm. Thus, a firm can be an innovator if it only implements TTP's developed elsewhere. In my conceptual framework different innovative implementations are different *technology generalizations*.

## **2.2 Generalizations Based on Special Technology Language or Technological Paradigm**

A key concept of this study is a *promising technological language or a paradigm based on generic technologies*. A generic technology functions well in many different types of products or production processes. Fusfeld (1978) illustrates this idea in the following way:

When we talk about technologies, we tend to speak of specific techniques and products - internal combustion engines, refrigeration, air conditioning, for example. But technology flows in and out of such products, and they do not provide the fundamental basis by which to measure technological change. The analysis must be on the level of *generic technologies*. A carburettor, for example, is an application of generic technology of vaporizing a liquid and mixing it with a gas.

The same technology applied in the paint industry might become an automatic paint sprayer or in the aerospace industry a jet backpack.

Dussauge et al. (1992,106-108) describe generic technologies as follows:

A technology is described as generic if - through combinations with other technologies - it is likely to lead to numerous different applications in diverse businesses. Unlike key technologies, generic technologies are not defined with reference to a particular business... Generic technologies are often closely related to fundamental scientific knowledge, precisely because they must hold the potential for generating a broad spectrum of applications.

The development of a technology is a historical or an evolutionary process. A technology has a genealogical line. A generic technology can be seen as a group of analogous inventions or innovations which have the same origin or ancestor (basic invention). Nelson and Winter (1977) have used the analogous concept "generalized natural trajectory" to describe cumulative clusters of innovations. Like in the evolutionary process of living nature the technological development is an interaction of processes which generate variations (inventions and innovations), transmit variations through time and space (learning and imitation) and restrict variations (selection as a result of competition and co-operation) (Pantzar 1991).

We might speak about *special technological languages or technological paradigms*. The second concept has been used in the new macro economics of technological development. The traditional "production function" viewpoint in economics has supposed that technological change is a global phenomenon without a specific direction. The new "Kuhnian viewpoint" of technological change refutes these assumptions (Dosi 1982). Dosi draws an analogy with Kuhnian philosophy of science (Kuhn 1970 orig. 1962) and assumes that "normal" technological change consists of relatively small improvements in bigger, revolutionary (and therefore "scarce") technological breakthroughs resulting in new technological paradigms.

According to Dosi (1982,152) a technological paradigm "embodies strong prescription on the directions of technical change to pursue and those to neglect". Practitioners typically become committed to "their" paradigm, which defines both how they understand and how they carry out their work. A paradigm is like a world view which an enterprise cannot easily change.

The macro economics of technological paradigms assumes that technological development is not based on unconnected techniques from which an enterprise rationally selects the most profitable ones of any moment in time. The discoveries



are supposed to be grouped into technological paradigms based on different technological breakthroughs. Analogous concepts to technological paradigms have been "technological regimes" (Nelson and Winter 1977), "technological guideposts" (Sahal 1981, Rip 1995) and "megatechnologies" (Kuusi 1991).

Dosi defined a technological paradigm as a "model and pattern of solution of selected technological problems, based on selected principles from natural sciences and on selected material technologies" (Dosi 1982, 152). Rene Kemp (1995) has defined a technological regime as

the overall complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, institutions and infrastructures which make up the totality of technology.

The definition of a technological paradigm also links up Schumpeter's innovation theory, in which an important innovation creates a bandwagon effect of smaller, incremental, follow-up innovations. Dosi (1982) uses a similar concept when he makes the distinction between technological paradigms and technological trajectories. In his view, "normal" technological change (compare the Kuhnian term "normal" science) takes place along a direction set out by the discovery of an important general principle which provides the opportunity for application in a number of economic sectors. A technological trajectory is the development of a technology along the lines set out by the technological paradigm (Verspagen 1992).

An important dimension of a technological paradigm is its pervasiveness. Perez (1983) has introduced the term techno-economic paradigm to make a distinction between pervasive and non-pervasive technological paradigms. A techno-economic paradigm describes the economic, institutional and technological interlinkages between sectors. A new technological paradigm will thus also imply a shift towards a new techno-economic paradigm if the technological principle (or the products associated with it) can be used throughout the economy, so that institutional and economic relations between all economic agents are affected.

Verspagen (1992) takes as examples of techno-economic paradigms steam power, electricity and iron/steel fall. Obvious current examples are revolutions in microelectronics and biotechnology. The takeoff of a techno-economic paradigm will require new investments and thus will imply the creative destruction of old capital in most sectors. The macroeconomic effects of less pervasive technological paradigms are much smaller. The main effect is limited to one or a few sector(s) of the economy.

What determines the competitiveness of a paradigm? Freeman (1991) makes a distinction between technological, economic and institutional factors in competitiveness. Technological competitiveness relates both to production costs (process innovation) and quality (product innovation). According to Freeman, technological competitiveness is increased by incremental innovations, which to a large extent take the form of learning effects. Due to their cumulative nature, the impact of incremental innovation and learning effects differ over the lifetime of a technology. Freeman assumes that in the initial (laboratory) phase of the development of a technology, progress may be very slow. But after a certain period of introduction, it is likely that incremental innovations and learning effects take place at increasing rates. In the later phases of the development of the paradigm decreasing marginal returns to research efforts might set in and learning effects become smaller and smaller.

Green et al. (1998) have made a distinction between techno-economic network (TEN) approach represented by Callon, Latour and others at the Ecole de Mines de Paris and the above discussed techno-economic paradigm approach (TEP). According to Callon (1992), "a techno-economic network is a co-ordinated set of heterogeneous actors... who participate collectively in the conception, development, production and distribution or diffusion of procedures for producing goods and services, some of which give rise to market transactions". According to Green et al. (1998,4-5), in a techno-economic network a variety of individuals with different interests are all able to realize their separate aims by the achievement of a common goal, with which all their interests become bound up. A bond between two actors in a techno-economic network is based on a *translation*. A translation defines the other, thus imputing it/him/her with certain interests, plans, desires and strategies.

According to Green et al. (1998,11-13) the TEP approach is a top-down approach. New (given) technological developments have to "fit" the appropriate social institutions for the TEP to take off. Green et al. consider that TEPs offer some understanding of how technological growth proceeds, but this approach does not explain how some technologies come to be selected in preference to others or how some succeed where others fail. As a down-top micro approach, the TEN approach provides these types of interpretations. The artifact/ social surrounds of an artifact are seen in a TEN as temporary and contingent. The scale of analysis is not predefined, but emerges within the analysis that starts from specific innovations. Translations do not have predetermined features.

I consider that the TEN approach has much in common with the approach of de Jouvenel discussed in the first chapter. Different actors have different pictures and strategies of the future (perceived interests and delegated subinterests in the conceptual framework of the GTC) which direct their behavior. These pictures or strategies are often not explicit. They can be inferred from e.g. instructions and

handbooks and/ or in the unwritten, physical attributes of made artefacts (compare Green et al. 1998, 17)

I think that a general idea which connects both TEN and TEP is that there are *common special technological future-oriented languages* shared by those having the same technological paradigm or by those working together in a network. The "grammar" of TEP language has more definite elements than the "grammar" of the TEN language. Using the concepts of the general linguistics of de Saussure (1916) a TEP language is more based on "Lang" (general codes) and a TEN language on "Parole" (special "speeches" of actors). I have hesitated if I should use the concept "special technology language" or "technological paradigm". I have decided to use the concept "technological paradigm", because I consider that the real long-term expertise concerning future technological development should be based on identification of definite elements of technological languages.

I consider that just the learning processes based on definite (invariant) elements of a common technology generalization language provide a practical way to define a technological paradigm. *I define a technological paradigm as a "shared generalization language" capable of producing important generalizations based on a cluster of linked technologies.* Generalization language of a technological paradigm has its particular criteria of sameness connecting its different generic technologies and it is based on perceived (e.g. scientific) invariances.

The role of a generic technology belonging to a technological paradigm can be illustrated by a biological analogy. Let us draw a parallel between a generic technology and a gene and between a successful product and a successful organism having the gene. As a gene with other genes, so a generic technology can function well only together with other generic technologies belonging to the same technological paradigm. A generalization language is a specific organization principle of generic technologies like a genome of a specie. A generic technology means that the "invention gene based on the generic technology" can function in many different types of technological paradigms or "genomes". If a product or production process, where the "invention gene" is applied, is successful, we may refer to an innovation. It is a new product or a production process based on some technological paradigm including the discussed generic technology.

A promising technological paradigm can be described by a group

[realized target(s), realized technique(s) to achieve target(s), promising new target(s), promising new technique(s) to achieve target(s)],

where the already realized target(s) or technique(s) for achieving target(s) can be generalized to many or important potential target(s) or other technique(s) for achieving target(s).

Let us look more closely at "a generalization based on a technological paradigm". Technology generalizations are based on similarity between already realized generalizations and promising generalizations. The basic argument of a generalization can be given as follows:

**Type 1 basic argument concerning a promising technology generalization:**

*Premise 1:* Technology generalization  $a_1$  is realized. This means that a target is achieved with a technique belonging to technological paradigm A.

*Premise 2:* Generalization  $a_1$  is *similar in technological paradigm A* to a not yet realized generalization  $a_2$ .

*Conclusion:* Generalization  $a_2$  is promising .

A simpler formulation of the type 1 argument is

A generalization  $a_2$  which is not yet realized is promising *based on paradigm A* because generalization  $a_1$  is realized.

Typically, the similarity between the two generalizations  $a_2$  and  $a_1$  is only partial<sup>2</sup>. They are similar based e.g. on a common target or a common technique. A technology generalization can happen both in the direction of new targets and in the direction of new techniques. Similar targets from the point of view of a technique need not be similar from the point of views of the customers having those targets. The above example of Fusfeld (1978) is illustrative: from the point of view of vaporizing a liquid and mixing it with a gas, applications in carburetors, in paint sprayers and in aerospace industry are similar. On the other hand, common targets might make technically very different techniques similar in technology generalization enterprises. The target of the inserting of foreign DNA into isolated cells of animals or plants illustrates the case (Moses and Moses 1995, 38). It is possible to meet the target using plasmids of bacteria, applying an electric current or by microinjection to inject a DNA solution directly into animal cells.

It is often difficult to find realized specific generalizations similar to a new possible generalization because of the tacit or hidden knowledge. In these cases, it is often reasonable to give a general description of the realized generalizations of the technological paradigm and to connect the promise of a generalization to that general evidence. The general evidence defines a group of similar generalizations based on some technological paradigm.

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<sup>2</sup> Many philosophers e.g. John-Stuart Mill, Peirce and many recent philosophers have tried to find objective measures for "argumentum a simile"(Niiniluoto 1987). My point is that the measures are always paradigm dependent.

## **Type 2 basic argument concerning promising technology generalization:**

A generalization is promising because it belongs to a *promising similarity group of generalizations based on a technological paradigm A*. The similarity group is promising because of the general evidence of theoretical considerations or because it includes realized generalizations.

Using the concepts of GTC, a technology generalization can be defined to be promising if its realization is within the perceived capability limits of an actor ("the group of actions, which the actor believes that he or she will not regret"). If the generalization is within the real capability limits of the actor, the actor does not regret its realization. *The fact that a generalization is within real capability limits of an actor (or many actors) is a way to define a technological innovation.*

The generalization based on some technological paradigm is an innovation process with a historical or time dimension. The innovation process starts if a generalization seems to be reasonable for at least one actor with enough economic and other resources. It is commonly recognized that there are two basic types of innovation processes: science push and demand pull. Irvine and Martin (1984) have depicted these two models of innovation in the following way:

### **SCIENCE PUSH**

Curiosity- oriented research ----> Applied research ----> Experimental  
development ----> Innovation

### **DEMAND PULL**

Market demand ----> Applied research----> Experimental development---->  
Innovation

I think that instead of "curiosity-oriented research" it is more reasonable to speak about "perceived promising technological possibilities (related to promising generic technologies)". Instead of "market demand" we might more generally speak about "promising new targets", which are also related to some actor based paradigm. From the viewpoint of an innovating organization the ongoing innovation process can be interpreted to be a "growth impulse" in its Bonsai tree or in its actor based paradigm. The starting impulse is situated in the top of the tree in a demand pull innovation process and in roots in a science push innovation process. In the case of a successful process the whole tree (generic technologies, skills and product branches ) should be in favour of the growth.

A practical way to conceptualize an innovation process is to describe its phases through the market position or the turnover of the products resulting from the process. It is reasonable to assume that the development is S-shaped (a form of a logistic curve). The reason for this form is that an application of a generic technology starts slowly and many impediments must initially be overcome. In the next phase the application advances rapidly for a period and then slows as the easy improvements have been "mined" (Rip 1995). An innovation process seldom leads to one product but to a series of products or innovations resembling each other.

The concept "technology generalization" is used instead of the commonly used concept "technology diffusion". Pekka Ylä-Anttila and Synnöve Vuori (1992) have described this concept in the book "Mastering technology diffusion" as follows:

The transfer of technology is seen as one form of diffusion. It is intentional and active diffusion encompassing flows of technological know-how and technical equipment from one country or area to another aimed to benefit both the supplier and recipient. Other forms of technology diffusions are spillovers, education, learning or other forms of "natural diffusion". The diffusion may take place across borders or within economies, i.e. it can be international or national. In general diffusion is viewed as a dynamic process over time during which the new techniques spread across the potential users once the innovation is adopted by the first individuals or firms.

According to Stan Metcalfe (1998, 7), "It is diffusion which is the crucial process in ensuring the spread of innovations to an ever widening circle of economic applications". A basic weakness in the concept "technology diffusion" is the at least implicit idea that the innovation adopted by the first individuals or firms does not change during its diffusion process. In practice, innovation changes or it is complemented by other (incremental) innovations in many or sometimes even most of its new applications. The idea of "generalization" is that new applications change a generic technology. A successful flow of technological know-how and technical equipment from one country or area to another normally requires incremental innovations. The successful applications (or generalizations) of a generic technology in a new country mean e.g. that new targets are met by that technology.

It is highly important to realize that the impacts of technological inventions (e.g. generalizations of generic technologies) also depend on generic ideas. De Jouvenel (1967, 258-266) considered that in addition to technological foresight, we need the foresight of social carriers of ideas: that is to say, their diffusion, deformations and applications. We may speak of socio-technological paradigms. These are clusters of generic technologies and generic ideas or social innovations.

Like generic technologies, generic social ideas diffuse through new generalizations. De Jouvenel (1967, 264-265) gave an interesting example of that. The American Declaration of Independence states that "We hold these truths to be self-evident; that all men are created equal; that they are endowed by their creator with certain unalienable rights; that among these are life, liberty and the pursuit of happiness". In the first phase this general idea was not generalized to concern slavery, at least in the minds of the slave owners who accepted it. This generalization happened, as we know, slowly: it was not fully enacted in practice until nearly ninety years after the Declaration of Independence.

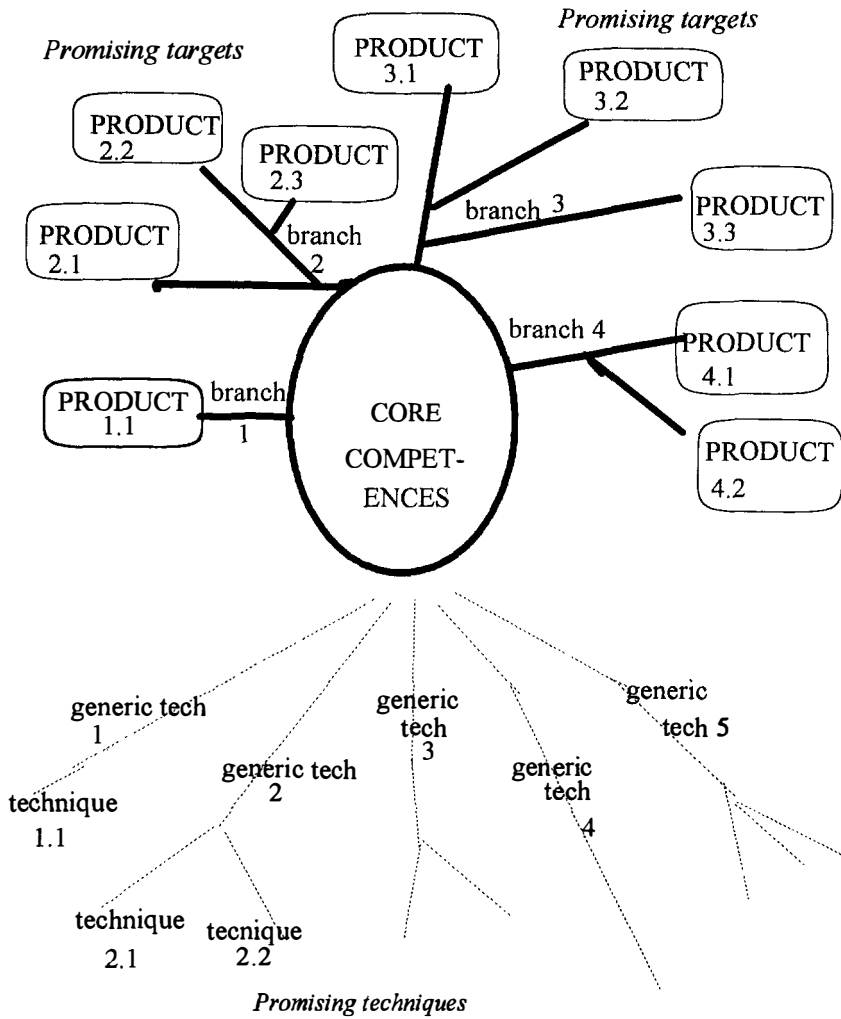
If the acceptance of a scientific idea or of a technological invention demands extensive deformations in the cognitive maps of people, it is not easily approved. If a technological invention contradicts a social innovation which many accept to improve their understanding of their genuine interests, it is easily rejected. These problems have been highly relevant concerning the inventions/innovations made in genetics. De Jouvenel (1967, 262), who discussed the diffusion of the ideas of Darwin, also anticipated the present discussion:

Take this example: in a country where, as in France, the state pays regular allowances to families with children, we would be deeply shocked by the suggestion that they should be denied to parents whose ancestors might have hereditary defects...Neither the idea of natural selection nor the subsequent ideas of genetics has been received in the social field. The powerful surge of moral ideas has swept them aside.

### 2.3 Technology Clusters or Application Paradigms of Actors

The micro- or meso-level counterpart of technological paradigm or of a special technological language is the technology cluster of some actors. Dussauge et al. (1992) have defined a technology cluster as a set of businesses sharing a common technological base. It consists of a number of applications, which relate the core technologies to products and markets. In contrast to a technological paradigm accepted by a whole community of actors, we might call the paradigm of a single actor an *application paradigm*. A technology cluster or application paradigm can be described as a "bonsai-tree", a Japanese term used in applications made by Honda, Canon and NEC.

Figure 2.1. Schematic Picture of a Bonsai Tree





The roots of a micro level bonsai tree are generic technologies, the trunk the technological potential developed by the firm, the branches the industries and businesses where the latter would be applied, and the fruits the products and product/markets (Dussauge et al. 1992, 105). In a meso level bonsai tree, the roots are also generic technologies, the trunk the technological potential developed by a developer community (e.g. the Finnish biotech community), the branches the industries and businesses where the latter would be applied, and the fruits the products and product/markets.

Two important elements mentioned already in the beginning of this chapter are added to the original bonsai tree model of Dussauge et al. (1992). They are promising targets and promising techniques. Based on already realized targets (e.g. products) and already realized techniques and competencies, a bonsai tree (or a technological paradigm) grows towards promising new targets and promising new techniques.

The technology cluster of generic technologies used by a firm described by a bonsai tree reveals the special logic in the growth of technology generalization firms, whereas the more conventional micro approach based upon business units would interpret this growth as diversification moves<sup>3</sup>. The trunk represents the "core competence" of the firm - a technical as well as industrial capability. The trunk represents a certain stability, whereas the roots consist of a set of ever-changing elements of the technological paradigm of a firm, some of which are growing while others shrink and are abolished, the main objective being to combine elements in the best possible way in order to nourish a durable trunk (Dussauge et al. 1992, 109).

Starting from the firm's products and markets, strategic segmentation is implicitly based on the idea of "industry"; however, industry is only one way of categorizing the firm's products. This concept is totally irrelevant in the case of firms growing in the technology-cluster mode. Firms or developer communities which grow as technology clusters do not compete in one specific industry, but in all the industries where their technological potential can provide them with an advantage. A competitor which is faster in mastering and applying new generic technologies thus represents a threat, entry into a given industry being a possible consequence of such advantages (Dussauge et al. 1992, 111). The technology-cluster strategy implies shifting from a financial (allocating resources to businesses) and marketing (concentrating on market share, industry attractiveness, etc.) logic, to a

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<sup>3</sup> The Bonsai tree has analogous features with the "theme pictures" discussed extensively by Cuhls (1998, 207- 287). They concerned e.g. the placement of solar cells and rapid nuclear reactors in the systems of targets. They represent policy visions of the responsible communities in Japan (e.g. of MITI). The method used by Cuhls seems to have many common features with the method, which I used in my study "A Coordinative Method for Social Policy Target Programmes" (Kuusi 1978).

capability<sup>4</sup> logic (exploiting the firm's technological potential) based on research and development capabilities (Dussauge et al. 1992, 114).

The capability logic is based to a large extent on network externalities. If there are enough exploiters of a technological paradigm communicating with each other and forming a part of a larger communication network in a market or elsewhere, it results in the increase of both incremental innovations and the number of users in the network. Due to specific historical circumstances, such as the existence of a competing technology or a specific institutional setting, a new paradigm may not reach this "critical mass" of users in some well-established production networks. This gives a chance for less well-established production networks of new or small firms.

## 2.4 How to Identify Technological Paradigms?

In practice the generalization of a generic technology with a new technique or a new target typically means a combination with the techniques or targets of other technologies. But how can we evaluate empirically which technologies might "co-operate" in generalization activities or might belong to the same technological paradigms?

Two methods have recently been used to analyse which technologies are close to each others. The first method is the content analysis of patent applications available through electronic databases. Like publications reflect the state-of-the-art of science, patents reflect the current inventive and innovative developments of modern technology (Engelsman and van Raan 1994, 3).

The references to other patents and common scientific concepts used in patent applications are evidence which can be used to build links between technologies or to find the directions of technology generalizations. In practice, Engelsman and van Raan (1994) have built technology maps as follows:

- 1) They used the patent data of the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) and aggregated the patent data into 28 fields of technology, following the work of Grupp and Schmoch (1992). These fields are defined with the help of International Patent Classification (IPC) codes. They cover the entire domain of technology, and are dif-

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<sup>4</sup> Here the concept "capability" is used in a different sense than in the GTC. There are, however, analogous features in the uses of the concept. "Capability logic" and "capabilities" refer skills and abilities of an actor. Analogously "capability limits" in the GTC are related to learned action possibilities taking into account the capacity limits and interests of the actor. Both interpretations are possible based on the Webster's (1996) definition of capability: "the ability to undergo or be affected by a given treatment or action".

ferentiated to emphasize recent high-tech developments. Therefore "traditional fields" (such as inorganic chemistry or building technology) tend to be larger in size (in terms of number of patents) than the more "modern" fields (such as genetics and electronics).

- 2) For the priority year 1987 they collected all indexed keywords in patent titles and patent abstracts for each of the 28 technology fields. Thus each field of technology is characterized by a specific set of keywords.
- 3) The 28 key word sets form a total set of key words. For the 28 fields they counted - field by field - the number of patents characterized by each of the key words in the total set. Thus they constructed a matrix of key words versus technology fields. Matrix rows are indicated by parameter  $i$ , matrix columns by parameter  $j$ .
- 4) They correlated these wordprofiles (or matrix columns) and obtained a correlation matrix (fields versus fields). The value in the cells ( $c_{ij}$ ) of this new "co-field" matrix is the correlation measure between field  $i$  and field  $j$  based on their common wordprofile.
- 5) The created co-field matrix gives us the relational strengths between all 28 fields one with another, and this relational structure can be displayed in two-dimensional space by multidimensional scaling.

The different patenting practices in different countries are a problem in the patent analysis. In Japan, patents have been a way to protect domestic market from foreign competitors. This patenting activity has been so extensive that in the worldwide patent database 1987/1988 half of the number of patents were national patents from Japan (domestic and foreign patents, all patents with the first priority being Japanese). The map in figure 2.2 is based on patents 1987/1988 excluding all national patents from Japan.

The applied mapping technique (multidimensional scaling) in principle puts fields with strong resemblance in the defining sense close together. Since only two dimensions are used, this positioning is not always perfect. To include the information on pair relations (field-field) as available in the co-occurrence matrix, a numerical value for these mutual relations was established, using a statistical index (Engelsman and van Raan 1994). These strengths are indicated by connecting lines, the thickest line representing the strongest relation.

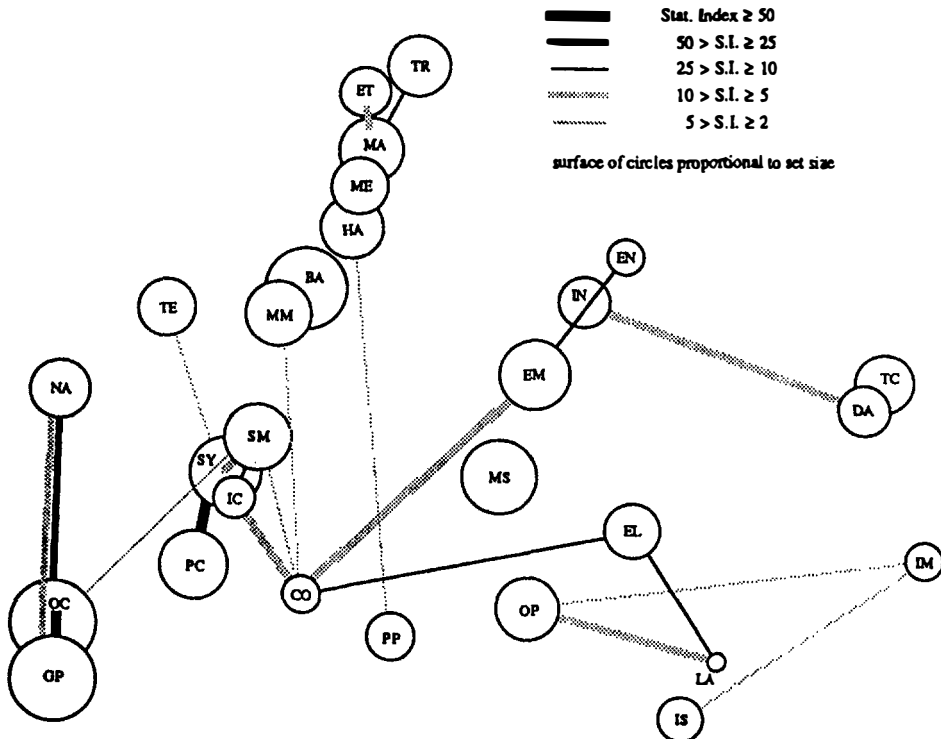
Figure 2.2. Co-classification map for EPO patents, database EPAT (1987/1988)

Code Technology Field

BA Mining, civil, engin., airconditioning,  
building materials, waste disposal  
PP Paper, printing  
TE Textiles, apparel, leisure, textile mach.  
ME Biomedical engin. (biomedicine)  
NA Agricult., nutrition, beverages, tobacco  
GP Bio- and genetic engin. (genetics),  
pharmacy  
OC Organic chemistry, petrochemistry  
PC Polymer materials (polymer chem.)  
SY Manufact. & appl. of polymers  
(Synthetic resins, paints, etc.)  
IC Inorganic chemistry, glass, explosives  
CO Coating, crystal growing  
SM Process engin., separation, mixing  
MA Mech. engineering, mach., armament  
MM Material processing, machine tools

Code Technology Field

HA Handling, conveyor equipm., robots  
TR Transport, traffic  
ET Engines, turbines, pumps  
EN Electric power, nuclear technology  
EM Electrical machinery  
LA Lasers  
OP Optimal equipment  
IN Instruments, controls  
MS Metrology, sensors  
DA Data processing  
IS Information storage  
TC Telecomm. (not image transmission)  
IM Image transmission  
EL Electronics, electronic components



Another way to find interconnections between different generic technologies is to ask experts about technologies belonging together. This type of process was realized in a technology foresight study accomplished by the Fraunhofer Institute for Systems and Innovation Research (ISI) in Germany (Grupp 1993b). I call the method "critical technologies' nearness mapping method based on expert judgments" or simply "critical technologies' mapping method" or CTM.

Grupp (1994, 380) has criticised critical technology studies outside Germany concerning the degree to which they specify technologies. Some of them are regarded as critical though they are defined very loosely; they do not allow any detailed recommendations or decisions of the technology policy to be made. According to Grupp the list of technologies was specified in CTM from the outset in much greater detail than in the comparable foreign studies. For example subcontractor agreements were made with institutes specialized in some topics.

The experts of CTM ("Projektträger"<sup>5</sup>) made firstly lists of technological topics ("technologische Themen") based on careful considerations concerning the possible technological areas (Grupp 1993b, 18-19). Beside negotiations among experts e.g. comparisons with studies made in the USA and in Japan were used. In a common meeting of experts a preliminary list of 103 technological topics was selected (Grupp 1994). The final list of 86 critical technologies (table 2.1.) was made combining some of the preliminary technological topics.

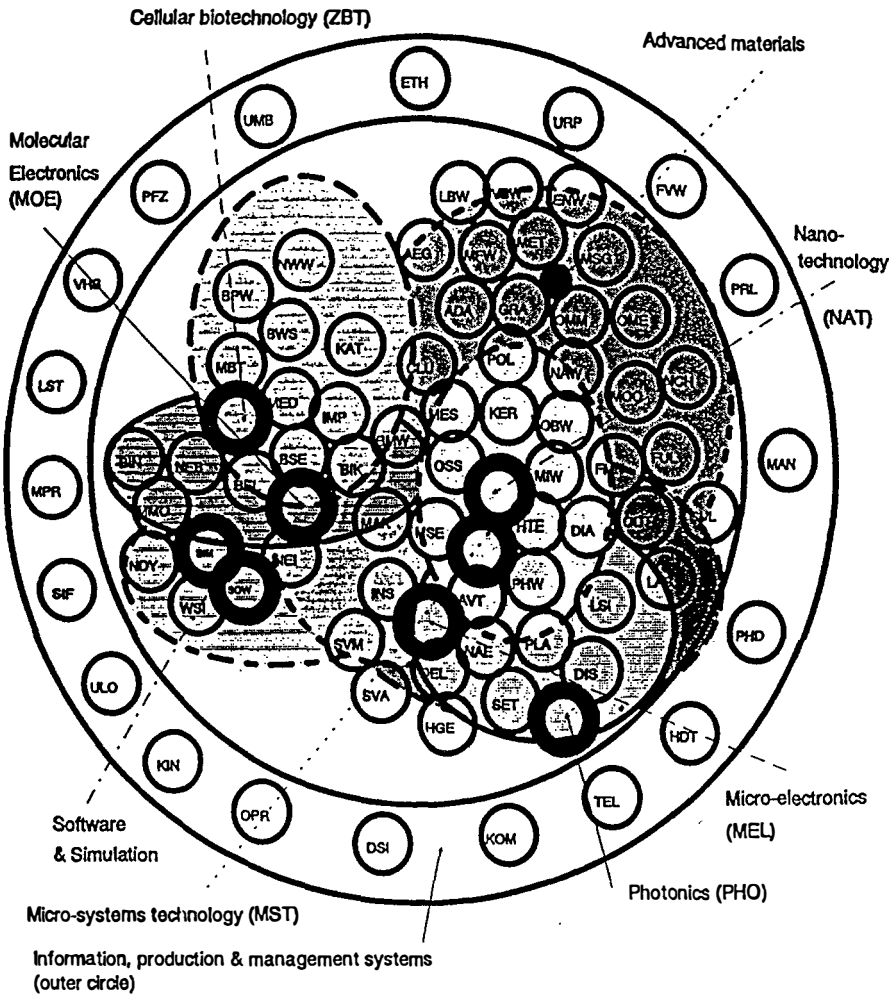
Based on different kinds of cluster analysis (Grupp 1993b, 26) an expert evaluation was made concerning "distances" of the critical technologies. In the distance map only five possible distances between the 86 critical technologies were used. The evaluation horizon was the next 10 years (Grupp 1994, 382). The closest interconnection got the distance of 1, the second closest distance got the distance of 2 and so on. If it was estimated that there was no connection between technologies they obtained a distance of 5. In reality this comparison of N technological topics produced an N-1 dimensional space. The method of multidimensional scaling was used, which transforms multidimensional distant data to two dimensional maps as in the case of patent analysis. This procedure produced the following interconnection map of different technological themes (figure 2.3, Grupp 1994).

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<sup>5</sup> "Projektträger" are in Germany those evaluators who know applications and make financial decisions concerning applications in research programs.

Table 2.1 List of critical technologies at the beginning of the 21<sup>st</sup> century

Generic headings and topics	Code	Generic headings and topics	Code
<i>Advanced materials:</i>		<b>Telecommunications</b>	<b>TEL</b>
High performance ceramics	KER	Broadband communications	KOM
High performance polymers	POL	Photonic digital technology	PHD
High performance metals	MET	Advanced broadcasting (HDTV, DAB)	HDT
Gradient materials	GRA	Optical computing	OPR
Materials for energy conversion	ENW	<i>Microsystems engineering</i>	MST
Organic magnetic materials	OMM	Microactuator technology	MAK
Organic electric materials	OME	Signal processing in microsystems	SVM
Surface and film technology	ODT	Microsensor technology	MSE
Surface materials	OBW	Mounting and connecting techniques	AVT
Diamond layers and films	DIA	<i>Software and simulation</i>	
Molecular surfaces	MOO	Software	SOW
Non-classical chemistry	NCH	Modelling and simulation	SIM
Meso-scale polymers	MES	Molecular modelling	MMO
Organized supramolecular systems	OSS	Bio-informatics	BIN
Clusters	CLU	Simulation of materials	WSI
Adaptronics	ADA	Non-linear dynamics	NDY
Multifunctional materials	MFW	Simulation in manufacturing	SIF
Lightweight construction	LBW	Cognitive systems (AI)	KIN
Composite materials	BVW	Fuzzy logics	ULO
Aerogels (solid foam)	AEG	Data network safety	DSI
Fullerenes	FUL	<i>Molecular electronics</i>	MOE
Material synthesis in standard shape	MSG	Bioelectronics	BEL
Implantation materials	IMP	Biosensor technology	BSE
Manufacturing of materials	FVW	Neurobiology	NEB
<i>Nanotechnology</i>	<i>NAT</i>	Neuro-informatics	NEI
Nanoelectronics	NAE	<i>Cellular biotechnology</i>	<i>ZBT</i>
Single-electron tunnelling	SET	Molecular biotechnology	MBT
Nano scale materials	NAW	Science-based medicine	MED
Manufacturing in micro- and nanoscales	FMN		
<i>Microelectronics</i>	<i>MEL</i>	Catalysis and biocatalysis	KAT
Information storage	INS	Biological production systems	BPW
Signal processing	SVA	Bionics	BIK
Microelectronic materials	MTW	Biomimetic materials	BMW
High speed electronics	HGE	Biological hydrogen production	BWS
Plasma technology	PLA	Renewable resources (biomass and agents)	NWW
Superconductivity	SUL	Environmental biotechnology	UMB
High temperature electronics	HTE	Plant breeding	PFZ
<i>Photonics</i>	<i>PHO</i>	<i>Production and management engineering</i>	
Opto-electronics	OEL	Management techniques	MAN
Photonic materials	PHW	Modelling in manufacturing	MPR
Laser technology	LAS	Control station technology	LST
Flat display technology	DIS	Production logistics	PRL
Luminous silicon	LSI	Lean-resource production	URP
		Behavioural biology	VBH
		Ethics in science and technology	ETH



The content of the connections between fields in the patent analysis and the content of the connections produced by the CTM differ. The connections in the patent analyses are based on realized recent achievements. Connections of CTM refer to expert perception of possibilities in the near future. It is interesting that there are, however, considerable similarities between the maps of the two methods. Both maps include clusters of items grouped around new biotechnology, new communication technology and new engineering or material processing techniques.

The three clusters mentioned are on the edges of the both maps. In the middle of the 1987/1988 patent map were electrical machinery, sensors and coating or crystal growing. In the middle of the map of the critical technologies' mapping method were organized supramolecular systems, micro-systems technology and nanotechnology.

What is the relationship between technological paradigms and the maps produced by the above methods? Grupp (1993b, 26) made an interesting remark: "Technological development at the beginning of the 21st century is not any more divided (auftrennbar) from the point of view presented here. So different the single lines of development might be, they finally all make impacts together (wirken alle zusammen)". Grupp's conclusion leads to an interesting question: are the different present technological paradigms actually paradigms concerning the "whole picture" of the technological development? Are technology generalizations related to general paradigms?

Personal or actor related technology application clusters or Bonsai trees provide an answer to the above question. It is reasonable to suppose that actors which have similar Bonsai trees can more easily communicate with each others. They typically have a "common language". As I have stressed earlier, just a common generalization language is the benchmark of a technological paradigm. Based on the results of the patent analysis and the critical technologies' mapping method, it is reasonable to suppose, that there are three comparatively separate technological languages related to the options of the new biotechnology, of the new communication technology; and of the engineering of new construction materials. There are, however, clear links between these technological languages related e.g. to the nanotechnology and coating or crystal growing techniques.

The paradigmatic languages are not, however, related only to common techniques. The basic "concepts" of paradigmatic languages are promising technology generalizations based both on promising targets and promising techniques. The topics of national technology Delphi studies, which will be discussed later, are very interesting from this point of view of technology generalizations: they can typically be seen to be single technology generalizations. In a paper which Martin Meyer and the author have prepared (Kuusi et al. 1999), we have illus-



trated a technological paradigm with the figure 2.4. This picture illustrates better than a Bonsai tree the generalization aspect of a technological paradigm.

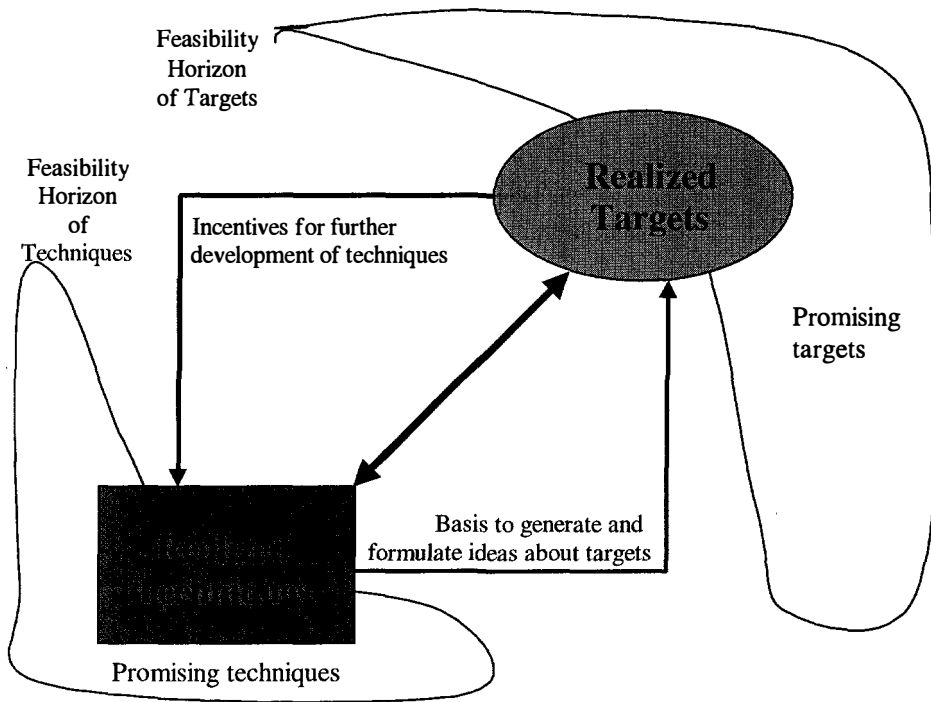


Figure 2.4. The "language" of a technological paradigm

It seems to be reasonable to assume that patents indicate rather well connections between techniques but less well connections based on similar targets. There is a similar problem in the application of the CTM. Actually Engelsman and Raan (1994) made a remark related to this matter. They considered that applied research publications may reflect technological innovations in specific fields better than patents.

Is it reasonable to suppose that there are common problems concerning new technology generalizations related to all technological paradigms or actor based technology application clusters? This question is related to evaluation criteria of technologies. An important part of the discussed study Grupp (1993b, 157-211) was an evaluation of technologies. All 86 critical technologies were evaluated based on 17 criteria. The evaluation criteria took clearly into account both the technique aspect (science push) and the target aspect (demand pull). The used evaluation criteria were divided in science push related ("Rahmenbedingungen") and in demand pull related ("Lösungsbeiträge").

The science push related criteria concerned R&D infrastructure, risks in scientific development of techniques, human capital, costs of innovation activities, relevance of scientific research for economic activities, national competitiveness, public support and international division of work. The demand pull related criteria were scope of potential technical applications ("key technology"-aspect), scope of economic applications (value-addition in many industries), helping of the position of small and medium size enterprises (promoting of a good structure of economy), competitiveness in relation to other countries, position of Europe in production of applications, dependence between European countries, impacts on health, impacts on social aspects (e.g. on good working conditions) and environmental impacts.

I will not continue in this connection the discussion about the evaluation criteria of technology generalization suggestions because it is the main topic of the next chapter. I mention only a basic problem related to expert evaluations based on above kinds of criteria. The evaluations provide subjective judgments ("proxy arguments") and seldom real informative arguments (with a real truth values) concerning potential technology generalizations.

The problem is related to the fact that the recent technologies are so complicated that it is typically very difficult to give understandable factual arguments in a general discussion like Grupp (1993b). Old simple technologies typically complemented or substituted basic human actions. It was possible to speak about replacement techniques (which allow to perform beyond the reach of the body), strengthening techniques (extending the performance of the body); and facilitation techniques (relieving the burden upon the body) (Rip 1995). In technologically developed countries it, however, it only seldom happens that a new application of a generic technology replaces a human function without the use of some earlier tool or technology. The technologies are substituting, complementing or quoting (often even plagiarizing) other technologies.

Technological replacement of human potentials is, however, still very relevant, considering human information processing skills. Frederick Brooks (Rheingold 1991, 37) has made an interesting functional division of the uses of the new information technology into artificial intelligence (AI) and intelligence amplification (IA):

In the AI community, the objective is to replace the human mind by the machine and its program and data base. In the IA community, the objective is to build systems that amplify the human mind by providing it with computer-based auxiliaries that do the things that the mind has trouble doing.

The roles of AI and IA in different connections depend on the strengths of computers and of human beings. Brooks saw three areas, in which human minds are more powerful than computer algorithms: pattern recognition, evaluations and the overall sense of context. Computer scientists do not have good ways of approximating the pattern recognition power a one-week-old baby uses to recognize its mother's face. The three areas in which present computers are more effective in the processing of information than human beings are according to Brooks evaluations of computations, storing of massive amounts of data and remembering things without forgetting.

The forms of substitution or complementation between technologies are manifold and it is difficult to find a really useful general classification for these forms. Fوسفeld (1978) has, however, suggested a classification which seems to be reasonable in many connections<sup>6</sup>:

1. Functional performance - an evaluation of the basic function that a device is supposed to perform. For example, the functional performance of a household refrigerator is to remove heat.
2. Acquisition cost - in the example of the refrigerator, the price per cubic foot.
3. Ease-of-use characteristics - the form of the user's interface with the device; in the example of the refrigerator, magnetic door latches and automatic defrosters contribute to the acceptance of the technology.
4. Operating cost- in the case of the refrigerator, the number of kilowatt hours used per unit of service performed.
5. Reliability - the question of how often the device or process normally requires service, how free it is from abnormal service requirements, and - ultimately - what its expected useful lifetime is.
6. Serviceability - the question of how long it takes and how expensive it is to restore a failed device to service.
7. Compatibility - the way the device or product fits with other devices in the context of the larger system.

Though it might be possible to compare single applications of technologies using above kinds of criteria, the comparison of technological paradigms or "technological languages" cannot be based on such kinds of simple criteria. Let us look closely at alternative paradigms around the generic heading "nanotechnology", which is in the middle of the map of Grupp (1993b). According to Grupp (1993b, 65):

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<sup>6</sup> In the epistemic utility model of technology generalizations which I will discuss in the third chapter the first, sixth and seventh criteria are connected mostly with impacts (I), the second, fourth and fifth criteria mostly with feasibility (F) and the third criterion with relevancy (R). It is important to notice that in case of a new technology option all properties of a technology are firstly non-validated suggestions (initially low value of V).

The nanotechnology will have a key position in the technological development of 1990s and in the first decades of 21. century. It makes possible the engineering in the level of atoms and molecules. This new basic technology can stimulate future innovation processes and new generations of technologies. It is based on the interaction of information technology, polymer research, optics, biochemistry and medicine and micromechanics.

Although the developer community of nanotechnology is still very diffuse, the approaches of its members can be divided in followers of two basic paradigms, which could be called top-down and down-top paradigms or approaches (Kuusi 1994, Bachman 1995). Looking at the present state of the art, they can also be called the near field probe systems approach and the protein chemistry approach (Meyer 1996).

In the first approach, microelectronics has a rather central position. It also has some common features with microsystems engineering (Grupp 1993, 90), one of the closest technological themes of nanotechnology in the German study. Microsystems engineering means top-down miniaturization to the micrometer scale. If the finest level of manipulation is one cubic micrometer, the "building blocks" still contain thousands of molecules. The top-down miniaturization might, however, contradict the forthcoming paradigm of the nanotechnology. According to one theoretician of nanotechnology, Eric Drexler (1995, 508), the methods of micro systems engineering "offer no obvious way to achieve the goals of molecular manufacturing". For Drexler the nanotechnology means essentially the same as the molecular nanotechnology, which he defines as follows (Drexler et al. 1991, 294):

Through, inexpensive control of the structure of matter based on molecule-by-molecule control of products and by-products; the products and processes of molecular manufacturing, including molecular machinery.

For this down-top paradigm of nanotechnology a very important step forward was a key innovation of biotechnology in the 1980s: the polymerase chain reaction. It routinised the multiplication of DNA. A challenge which stimulates the down-top developers of nanotechnology is the following possibility mentioned by Ted Kaehler: "There may be other polymers whose synthesis chemistry is easier than that of peptides, whose side groups take more volume and whose folding is more predictable" (Kaehler 1994 c.i.f. Meyer 1996).

In summary, how to proceed in the practical identification of technological paradigms? I consider that the earlier mentioned remark of Grupp (1993b, 26) is very important: recent technological paradigms are not related to one or few technolo-

gies but they are different kinds of "whole pictures" of the technological development. A promising way to identify technological paradigms might be firstly to construct total maps of generic technologies perceived by single experts. Relevant descriptions of technological paradigms might be found by comparing these total maps of interconnected technologies. A reasonable hypothesis is, that the actor based total paradigms might focus on the new biotechnology, the new communication technology or the new engineering or material processing techniques. The result might, however, be also paradigms with some other organising principles like the top-down and the down-top principles discussed above.

## **2.5 Developer Communities as Sources of Expert Knowledge concerning Future Technology Generalizations**

The concept of a developer community of a technological paradigm is a key concept of this study. It connects the theoretical and empirical considerations of the study. It has two main functions. Firstly, the developer community is the source of expert knowledge of a cluster of generic technologies or closely linked actor based technological paradigms. Secondly, it is the main user of technology foresight studies concerning the technological paradigm.

Technology foresight based on expert knowledge is very much a "self-reflection activity" of a developer community. Technology foresight is based on a critical examination and an amplification of the competence which a developer community already has. Typically, the successfulness of a technology foresight enterprise depends on the very same developer community from which the expert knowledge has been collected. If the developer community cannot utilize the results, a technology foresight study is often useless. The commitment of the developer community to the results of a technology foresight study is crucial (e.g. Georghiou 1996, 368).

A developer community includes not only producers, who use the new technology, but also the buyers and users of their products. A good starting point for the analysis of developer communities are Michael Porter's famous "diamonds" of competitive advantage based on factor conditions; demand conditions; related to supporting industries; and firm strategy, structure and rivalry (Porter 1990, 71):

Firms gain competitive advantage where their home base allows and supports the most rapid accumulation of specialized assets and skills, sometimes due solely to greater commitment. Firms gain competitive advantage in industries when their home base affords better ongoing information and insight into product and process needs. Firms gain competitive advantage when the goals of owners, managers and employers support intense commitment and sustained investment.

The point of Porter can be given very simply: the competitive advantage is based on the committed and informed actions of different stakeholders in a developer community.

A technology community may or may not have a clear structure of interaction and decision-making. It has an active or influential core, in which members have a dominant technological paradigm as their "world view" and a critical, passive or powerless periphery, in which members are often critical to the paradigm. Today, large multinational corporations (MNCs) are usually at the cores of developer communities. The structures of developer communities are greatly influenced by the networks built by MNCs e.g. how they use subcontractors and which connections they have with customers, financial institutions, educators and public regulators.

For example, the Nokia company accounted for some 20% of the total Finnish foreign exports in 1998 was about 20% and most Finnish exports of telecommunication equipments happened through the cluster led by Nokia. It is an interesting question what should be the role of the experts of Nokia in the foresight studies of digital data technology in Finland when most of the production using this technology is directly or indirectly governed by Nokia.

Seija Kulkki has published a study on knowledge creation in multinational corporations, which she calls "a realist, contextual and processual multiple-case study" (Kulkki 1996, 95) of three Finnish companies including Nokia Telecommunications. It is obvious that the findings of Kulkki are highly relevant if one is interested in finding those persons who are most competent to evaluate the future applications of digital technology in Finland and even at the global level.

It is, however, a mistake to believe that in general the present dominant decision-makers of applications of a generic technology are the most valuable experts, especially in a public future technology study. Firstly, other persons may be better informants than the important decision-makers themselves concerning their real plans or their organizations' future decisions and actions as is more closely discussed in chapter 5. Secondly, dominant decision-makers are often so closely committed with the dominant technological paradigm that they do not easily accept even reasonable arguments if they are in contradiction with their paradigm.

In general, if one likes to make realistic evaluations of the future possibilities of a generic technology, the scope of a developer community or a technology community should not be restricted even to those actively participating in innovation processes. Nelson (1993) mentions firms, industrial research laboratories, research universities, government laboratories, schooling institutions and financial institutions as major institutional actors of a technology community. I think that this list of institutions is too short. The regulative activities of civil servants and

civic organizations (political parties, Greenpeace etc.) are often crucial. It is vital to notice that active critics of the technology also belong to its developer community.

A good example of a developer community which is defined broadly enough is given by Sirkku Kivisaari (1996). She described business relationships of a technology generalizing firm in the health sector. Beside suppliers, distributors, customers, medical research institutions and external sources of finance; she mentions policy makers, standard setting bodies and organized social actors.

A practical way to define key representatives of a developer community was used in the UK Technology Foresight Programme (Georghiou 1996, 367). The idea was to use the community itself to identify those who should represent it in a Delphi study. The selection process was based on asking each respondent in a selected group to identify further individuals, who met the criteria of being good representatives of the community. Similar "snowball sampling" was also used in Finnish Delphi studies by Kuusi (1987,1991,1994).

The relevant criteria for being a good representative of technology community are a problem in the "snowball sampling". In the British study, two main criteria governed the selection of the panellists: first that there should be sufficient expertise to answer the questions posed, and second that there should be a reasonable balance of different types of experts (Georghiou 1996, 369). Given examples were balances between industry and academia and between regions. A difficult problem is how to find enough representatives of different technological paradigms when the representatives of different paradigms sometimes do not accept the representatives of rivaling paradigms as competent experts. More generally, the critical stakeholders do not easily win acceptance as experts from the other experts.

The scope or the limits of a developer community change continuously. A technology foresight study can broaden the group of people who belong to the community. It can also have an impact on the structure of the community. If a foresight study results in a redefinition of the paradigm, some persons or institutions who were earlier in the periphery may move to the core of the community.

The best experts of a generic technology are typically active participants in a world-wide developer community. The world-wide developer community consists further of national developer communities interacting with each other. Interaction networks of members of a developer community are partly international and partly national or even local. Nelson (1993) proposes that just as the idea of national innovation systems has become widely accepted, technological communities have become more international than ever before.

I think that the successfulness of a technology foresight study depends foremost on the competence of the technology foresight study managers to handle the social dynamics of relevant developer communities. Such competence is needed in the selection of the expert panel and in optimising the communication process of the panel. Experts in basic research or in education, experts in realization organizations of technology generalizations, experts in public regulative organizations and other relevant stakeholders (e.g. political parties, consumer organizations, environmental organizations, trade unions) have very different kinds of motives for participation and in information transmission in technology foresight studies.

The concept of the developer community is analogous to the concept of "scientific language community" used by the late Thomas Kuhn (Kuhn 1991). According to Kuhn, strong evidence (e.g. an argument concerning the future) for one community does not need to be evident for another. Like a language community, a technology community has a core and a periphery. Actors in the periphery have to accept the lexicon of the community or the "rules of game" to have an influence on the behaviour of the community. On the other hand, those in the core are capable of changing the rules of the game, that is the acceptable arguments concerning the future.

## **2.6 Promising Generalizations as Leaps into the Unknown**

A basic difficulty of technology foresight is that every innovation process is a leap into the unknown. The considerations based on similarities of realized and promising generalizations and theoretical considerations of new links between some generic technologies provide only crude lines for anticipation of innovation processes.

The management of uncertainty seems to be a key problem of a firm which tries to cope with an economic environment which continuously changes in response to new innovations. Eliasson (1996) has presented a general economic theory concerning "the experimentally organized economy", which seems to describe the behaviour of firms in this type of economic environment. Eliasson (1996, 54-57) considers that an experimentally organized economy forces the firm to be organized as "an experimental machine".

First, technological competition constantly downgrades the economic value of the competence of knowledge capital in firms. The prime task of top level corporate management is to organize its human capital through recruitment, replacement and internal education to steadily upgrade its competence base. Eliasson considers that the experience has shown that it is more difficult and takes more time to adjust obsolescent competence capital (embodied in people) to the requirements of new market situations than it is to change other assets on the balance sheet.



The reason is that it requires competence to change competence capital (or technological paradigm, author's addition), and this was usually missing in the first place when a firm encounters major problems. Hence the solution is to change the key persons of the organization, those who make the top-level decisions, notably on recruitment and restaffing.

Second, technological competition among a large number of firms in global markets, facing a virtually unlimited number of more or less well-defined investment opportunities (or technology generalization opportunities, my addition), pushes firm management to take action long before they confidently know what steps to take. Eliasson considers that the guiding management principle in the experimentally organized economy is that if you have an idea that you consider good you had better realize it as a business very soon, because if it is good, a competitor might otherwise do so before you, and beat you. Hence, it is risky for top-level management to exhibit risk aversion. Firm management, therefore, faces two kinds of failure:

- First order risk; of making a mistake by being too early,
- Second order risk; of being beaten by a competitor for being too late.

In the next chapter, I will discuss three types of reasonability continuing from the classical analysis of Herbert Simon (March and Simon 1958) - prediction reasonability, option reasonability and commitment reasonability - needed in an economic environment which continuously changes based on new innovations. I will also present an epistemic utility model which connects the technology foresight to these types of reasonability.

There are four basic types of uncertainties in a technology generalization process:

- the aimed technique cannot meet the target;
- there is some other technique, which is more efficient in achieving of the target;
- the target is not good enough (e.g. economically, socially or environmentally);
- and
- the technique is not acceptable (e.g. economically, socially or environmentally)

All these types of problems can stop an innovation process. Often, however, after a search process a new feasible generalization based on the technological paradigm is found. Sometimes, a radically new type of solution is found and it is reasonable to speak about a new generic technology or sometimes even about a new technological paradigm. In the cases of very important targets or of large sunk investments, the search process may continue for a very long time, though it has reached rather meager results. For example, the innovation processes aiming at commercial nuclear fusion power have struggled for decades with the problem of how to keep the hydrogen long enough at a temperature of ten million degrees.

Reasonable technology foresight requires least a vague idea how to meet any discussed target. Irvine and Martin (1989, 17) have expressed a similar viewpoint concerning research foresight:

Unpredictability is greatest in curiosity-oriented research, and it would be foolish in the extreme to pretend that it is possible in any reliable way to foresee the fundamental breakthroughs which periodically revolutionize our understanding of world, as well as opening up entirely new technological possibilities over the longer term... Our principal concern, therefore, is with strategic research where the time-scale for implementation of results in new products, processes or services is typically a decade (although it can be as little as five years in some areas and up to twenty or thirty in others).

It might be reasonable to have a topic in a technology foresight study, which seem to be out of reach. Some panellist might have an idea, how to achieve the topic. An active search might result in a success. For example in the Second World War, Germany succeeded in the finding of a technique for producing artificial rubber used in tires (Freeman 1982). I consider, however, that if at the end of a Delphi exercise there is no idea, how to meet a target, it is not very reasonable to anticipate the attainment of the target.

So, at least at the end of a foresight process any reasonable option should be based on technique-target relationships motivated by generic technologies or by a technological paradigm. This idea is the starting point of the epistemic utility model, which will be presented in the next chapter. A technique may be only theoretically feasible based on the applied technological paradigm. But also in that case, it has to be a result of logical reasoning from some promising generic technology and supported by scientific laws or invariances of the technological paradigm.

Pure basic research often finds means to targets earlier out of reach. It is, however, impossible to anticipate these findings. Recent inventions made in pure basic research may be, however, good starting points for the technology foresight.

In practice, almost every decision to allocate considerable resources to an innovation process aiming to a target is based on some at least vague idea how the target can be met. A fundamental problem in technology foresight is, that this idea often belongs to tacit or hidden knowledge. The problem of tacit or hidden knowledge is closely discussed in the following chapters. A key question of this study is, how to change tacit or hidden knowledge to the object of argumentation of experts making it explicit.

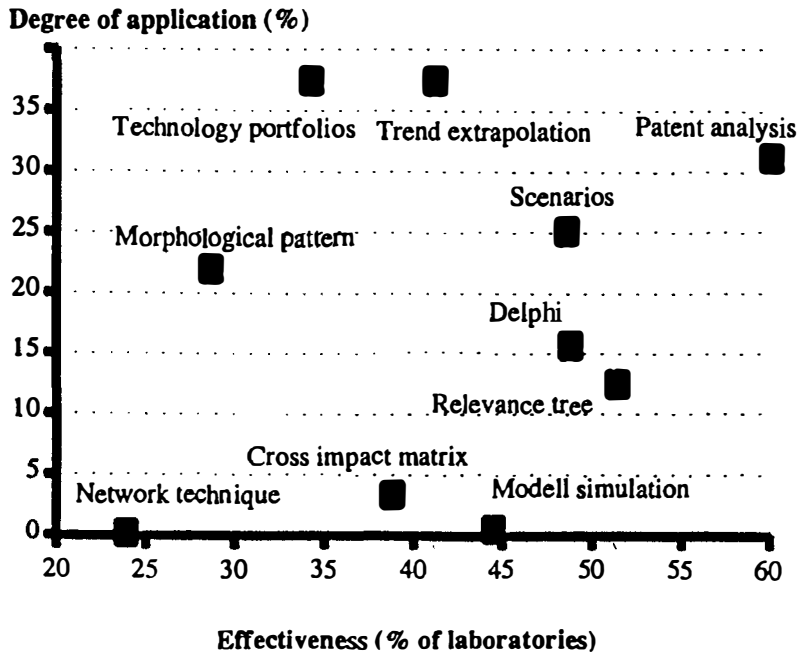
### **3. EPISTEMIC VALUE OF DELPHI ARGUMENTS AND TECHNOLOGY FORESIGHT**

#### **3.1 Different Interpretations of the Delphi Method**

According to Jay Gordon et al. (1993), the modern renaissance of futures research began with the Delphi technique at RAND, the Santa Monica, California "think tank" in the early 1960's. On the other hand, some researchers have denied the value of the Delphi method nearly totally, at least in its traditional form. I will discuss the crushing critic of Sackman (1975) in the next paragraph. At the end of his long review article, Fred Woudenberg (1991,131) made the following conclusion: "The data discussed in the present article leave no other possibility open than for a negative evaluation of quantitative Delphi. The main claim of Delphi - to remove the negative effects of unstructured, direct interaction - cannot be substantiated."

At least in the area of technology foresight it is, however, difficult to deny the practical usefulness of Delphi studies. A Japanese study compared the methods used by Japanese research units in technology assessment (Grupp 1993, 13, Cuhls and Kuwahara 1994,3). The study was made in 1989 and 247 participating research units, mostly working in industry, were asked to evaluate their methods of technology assessment. Figure 3.1 contains a summary of the results of the study. The vertical axis shows the number of enterprises, which have used the method. The horizontal axis describes the number of user firms, which evaluated that evaluated the method successful.

Figure 3.1. Degree of application of technology foresight tools in Japan



The technology portfolio method and trend analysis were used most. These methods, however, did not rank very high in usefulness. Patent analysis received the highest value in usefulness. A limitation in patent analysis is its time horizon. It provides good information for only five years forward. Scenarios, Delphi and relevance tree methods ranked second in usefulness.

Although the Delphi method has been used for already fifty years, the opinions about its relevant features differ greatly. More than twenty years ago, when Harold Linstone and Murray Turoff wrote an introduction to the extensive survey book "The Delphi Method", the variety of applications of this method was very wide concerning both methods and contents (Linstone -Turoff 1975). The wide variety is pronounced in the very general description of the Delphi technique, which according to Linstone and Turoff can be taken as underlying the contributions to their book:

Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.

Group communication processes used to deal with complex problems have the following logical phases ( Linstone-Turoff 1975, 5). The first phase is characterized by exploration of the subject under discussion, wherein some persons contribute additional information which they consider pertinent to the issue. The second phase involves the process of reaching an understanding of how the group views the issue. If there is significant disagreement, then reasons for the differences are explored in the third phase to bring out the underlying reasons for the differences and possibly to evaluate them. The last phase, a final evaluation and conclusions, is based on all previously gathered information.

The characterization of the Delphi method given by Linstone and Turoff is very general. According to Gordon (1993, 4), anonymity and feedback represent the two irreducible elements of a Delphi study. Traditionally, a third feature has also been connected with the Delphi method: consensus seeking. Dalkey and Helmer gave the following objective to the Delphi method at the beginning of 1960's: " to obtain the most reliable consensus of opinion of a group of experts... by a series of intensive questionnaires interspersed with controlled opinion feedback" (Linstone- Turoff 1975, 10).

Woudenberg (1991, 133) gave three characteristics of Delphi as it was originally developed:

- Anonymity. Participants, mostly experts, are approached by mail or computer
- Iteration. There are several rounds. The first round can be inventory, in which participants are asked for events to be forecast or parameters to be estimated. In subsequent rounds, participants are asked to give quantitative estimates about dates of future events or values of unknown parameters. The number of rounds is fixed in advance or determined according to a criterion of consensus in the group of participants or stability in individual judgments.
- Feedback. The results of an eventual first inventory round are clustered and sent back to all participants. In the first estimation round, participants give their quantitative estimates. Before the second and subsequent estimation rounds, the results of the whole group on the previous round are fed back in a statistical format (measure of central tendency plus variance) to all participants. On the second and subsequent estimation rounds, participants making judgments that deviate from the first-round group score according to a fixed criterion are asked to give arguments for their deviating estimates. Before the third and subsequent estimation rounds, these arguments are, along with the statistical results, fed back to all participants.

Rowe et al. (1991, 237) presented a very similar list of basic features of a Delphi procedure. The only difference was that they divided "feedback" into two items: "controlled feedback" and "statistical group response".

The basic features of the Delphi method have given grounds for different interpretations of "the point" of the Delphi. Saaty and Boone (1990, ref. Lang 1996) have argued that there are four defensible ways of forecasting the future. One is by consensus, the second is by extrapolating on trends, the third is by historical analysis and analogy and the fourth is the systematic generation of alternative paths to the future. Delphi is considered the most prominent of the consensus methodologies (Jones 1980).

Mike Metcalfe (1995, 79) has stressed the lack of group dynamics:

The idea of the process traditionally known as the Delphi technique is to obtain a group forecast while keeping the group dynamics to a minimum. The physical, and thus psychological, distance between the members of the forecasting group is maximized... The point of the exercise is to provide an egalitarian system of forecasting.

Metcalfe sees the Delphi process as an alternative for a working group or a committee of experts. The common feature of an expert committee and a Delphi study is group communication between experts. But the essential difference is that a Delphi study it avoids, the group dynamics of a committee and especially their bad effects on innovativeness and objectivity.

Turoff (1975, 86) have pointed to the problems associated with committees, which are especially urgent in the phase of seeking future alternatives:

- The domineering personality, or outspoken individual that takes over the committee process
- The unwillingness of individuals to take a position on an issue before all the facts are in or before it is known which way the majority is headed
- The difficulty of publicly contradicting individuals in higher positions
- The unwillingness to abandon a position once it is publicly taken
- The fear of bringing up an uncertain idea that might turn out to be idiotic and result in a loss of face.

Similar reasons for anonymity were given by Hiltz and Turoff (1995):

- Individuals should not have to commit themselves to initial expressions of an idea that may not turn out to be suitable.

- If an idea turns out to be unsuitable, no one loses face from having been the individual to introduce it.
- Persons of high status are reluctant to produce questionable ideas.
- Committing one's name to a concept makes it harder to reject it or change one's mind about it.
- Votes are more frequently changed when the identity of a given voter is not available to the group.
- The consideration of an idea or concept may be biased by those who introduced it.
- When ideas are introduced within a group where severe conflicts exist in either "interests" or "values", the consideration of an idea may be biased by knowing it is produced by someone with whom the individual agrees or disagrees.
- The high social status of an individual contributor may influence others in the group to accept the given concept or idea.
- Conversely, lower status individuals may not introduce ideas, for fear that the idea will be rejected outright.

An indication of the profound differences in interpretations of the Delphi method is that Millett and Honton (1991) even included the Delphi method in "group dynamics methods". In their short introduction of the Delphi as a consensus method, they even recommend contacts between panelists (Millett and Honton 1991, 52):

The Delphi managers put together a list of experts to complete the questionnaire. The experts do not have to be convened as a group, but they can if circumstances permit.

### **3.2 The Critic of Sackman**

The basic difficulties of the traditional Delphi method are widely discussed by Harold Sackman in his book *Delphi Critique* (Sackman 1975). The emphasis in the book was on scientific appraisal of the principles, method and practice of Delphi. Though Dalkey (1967), Gordon (1969), Helmer (1967) and Kaplan et al. (1950) had given theoretical motivations for Delphi studies, Sackman considered that in 1975 there was virtually no serious scientific literature on Delphi based on evaluations of accomplished Delphi studies.

The focus of his study was the scientific evaluation of about 150 Delphi studies conducted by the Rand Corporation and elsewhere before 1974. Based on his evaluation discussed below, Sackman (1975, 3-4) concludes that conventional Delphi is basically an unreliable and scientifically invalidated technique in principle and probably in practice. Sackman considered that even variations of con-

ventional Delphi should not be encouraged unless they explicitly attempt to meet the challenge of generally accepted standards of rigorous empirical experimentation in the social sciences at least so long as its principles, methods and fundamental applications can be experimentally established as scientifically tenable.

Beside the evaluations of the Delphi studies already undertaken, the critique of Sackman is based on some assumptions concerning the method. Because my analysis is limited to knowledge about the future, I limit my discussion to the points which are relevant for that purpose:

1) Sackman mentions four application objectives of the conventional Delphi, which are relevant for futures studies. The first is the *forecasting* of specified events. The second are *qualitative evaluations* (qualitative scales of agreement, preferences among alternatives). These applications include any type of quantitative or qualitative rating scales and as such are coextensive with questionnaires broadly considered. The third objective is the *consensus among the participants*, which is sought through a controlled and rational exchange of opinions. The fourth objective mentioned by Sackman is *educational*: the Delphi study may help participants, Delphi managers, and the users to explore a problem more thoroughly.

2) Conventional Delphi is *primarily concerned with experts*, but may also use other subject groups.

3) Sackman considered that the main technical features of the method were *anonymity, feedback and iteration*.

The basic critique of accomplished Delphi studies was based on evaluative criteria quoted from "Standards for Educational and Psychological Tests and Manuals" of the American Psychological Association (Sackman 1975,11). These standards were based on the many critical studies concerning predictions of social events (e.g. Kaplan et al. 1950). According to Sackman, the general conclusion of the studies behind the standards was as follows (Sackman 1975,12):

A questionnaire is reliable and valid only to the extent that it is administered under conditions that replicate the basic experimental controls under which it was originally designed, tested and validated.

According to Sackman, Delphi iteration of questionnaires with feedback is a definite empirical experimental procedure with human subjects in its own right. Neglect of standard experimental guidelines may lead to uncontrolled variations in results and inability to define, replicate and validate method and findings. This neglect may be acceptable for an informal exploratory technique, but is unacceptable for a rigorous social science experiment.



Based on the standards considered essential by the Psychological Association, Sackman made following conclusions from the 150 Delphi studies (Sackman 1975, 15-27). I give letter codes to his arguments for further discussion.

*Statistical significance of the evaluations*

A. The statistical significance of a relationship is rarely reported in Delphi studies. A consensus among the panellists and the precision of the evaluations is not implied from standard error estimates. Analysis of the variance of test scores is seldom made.

B. The documentation should report whether scores vary for groups differing in age, sex, amount of training, and other equally important variables. Sackman considered that the tacit Delphi assumption is that the pooled opinion of experts is better than that of any subgroup of experts.

C. The number of independent judgments by experts is not reported. The requirement concerning independent judgments goes to the heart of Delphi iteration "with feedback". All rationalizations about reconsidering, incorporating new information, and converging toward consensus cannot hide the fact that independent judgment is destroyed.

*Predictive validity*

D. Empirical validity is commonly not tested. Panel opinion is reported with little or no subsequent effort to test results against actual and related events. The Delphi method typically measures very small sample attitudes toward future events at a given time.

E. The average evaluation of the experts of the future is typically not better than in a simple projection. Sackman's example is eight independent expert forecasts of the US gross national product from 1953-63 (Zanowitz 1965). The average observed absolute error for experts was \$10 billion. Zarnowitz found that simple arithmetic extrapolation of the increase occurring in the previous years, yielded an average absolute error of \$12 billion.

*Content validity*

F. Content validity is rarely evaluated. This validity requires that the documentation should clearly indicate, what universe is represented and how adequate the sampling is. The example of Sackman is a study of future computer developments (Parsons and Williams 1968). Sackman considered that content validity preparation would call for a systematic taxonomy of hardware, software, peripheral

equipment, communications and applications. The correspondence between final selected items and the specified area should be spelled out.

G. The documentation had not indicated the are in accordance extent, to which interpretations matched hypotheses derived from the theory. The reasons, theories, and hypothetical constructs of expert panelists have been in Delphi studies covert, rather than overt. Panelists are asked for opinions, and the occasional rationale from panelists has been typically very brief, uneven, and often absent in final reports.

#### *The reliability of results*

H. Reports of reliability studies are not ordinarily expressed in terms of variances for error components or standard errors of measurement. Dalkey (1969) had made an initial attempt in this direction by indicating the increasing reliability of medians with an increasing sample size of panelists. Dalkey had presented split-half (odd-even) reliability for some results. The reported level of reliability had been marginal for useful questionnaires.

I. Documentation should indicate to what extent scores are stable, that is, how nearly constant the scores are likely to be if the test is repeated after time has lapsed. No such replications were reported in the Delphi studies analyzed by Sackman.

#### *The expertise and the representativeness of experts*

J. The study documents should describe the relevant professional experience and qualifications of the experts. Delphi exercises guarantee the anonymity of individual responses, which is typically interpreted so that scarce information is reported concerning the panelists. Some studies have listed the names of panellists and, in fewer cases, their professional affiliations. Sackman found no study listing professional training and scaled experience levels qualifying each individual as possessing the skills required to meet an objective criterion as an "expert".

K. Delphi studies typically do not report the key population characteristics of panellists. Such specification of "expert" sampling would permit more effective evaluation of the adequacy of the expert sample. For example, a long-range forecasting study might benefit from the inputs from relatively youthful panellists, lower-class or minority members, more women panellists or wider geographical distribution of panellists.

L. Panellists dropout has been a well-known hazard of Delphi. The validity of sampling requires that probable selective factors and their presumed impact on results should be stated. Sackman cited Bedford (1972) who noted that dropouts

in a study on home communication services were less motivated to participate in the study and were more critical of the overall study and the utility of questionnaire items.

M. Delphi practice dissociates itself from any systematic analysis of second-string concurrent criteria (e.g. short-term interpretations of long-term trends). Panelists often disagree over what exists "today," and with rare exceptions, Delphi practitioners make no effort to present panelists with a precise report on "where we are".

### 3.3 Answers to the Critique of Sackman

In the recent national technology Delphi studies, large samples of experts have been used and the basic conventional criteria of statistical significance have been met much effectively than in the earlier studies. From the statistical point of view, the critique of the points A, B, D, H, I and L is not very relevant concerning these studies.

I, however, consider that Sackman ignores the special point of Delphi studies. Sackman's critique was based largely on the comparison of the scientific criteria of opinion polls with Delphi studies. Actually, Sackman (1975, 3) suggested rigorous questionnaire techniques and scientific human experimentation procedures as preferable alternatives to the conventional Delphi.

There are, however, fundamental epistemic differences between opinion polls and Delphi studies, as I understand their roles. The basic difference can be stated as follows: The idea of opinion research is to find opinions or behavioral dispositions (transient invariances) of the persons studied or of the base group from which the study persons are sampled. *The main idea of a Delphi study is to find relevant arguments concerning future developments.*

The above idea of the Delphi study is clearly visible especially in the Policy Delphi (Turoff 1975) and different later variants of it. I will later evaluate the Policy Delphi and present my own variant: the Argument Delphi. The above idea is clearly visible in a Delphi variant called the Qualitative Controlled Feedback (QCF) (Passig 1998, Press 1983). This variant does not require that the panelists make common judgments as groups. The QCF feedback is qualitative rather than quantitative, which means that statements explaining individual judgments rather than group response means and standard deviations are provided as feedback. These qualitative responses may contain information, insights, perspectives and nuances not provided in quantitative responses. The QCF does not attempt to achieve consensus. Although the majority or all of the participants may agree on one or more items, consensus is never suggested as the process goal.

Based on the above main idea of the Delphi study, I will illustrate the difference between an opinion poll and a Delphi study with a possible future event discussed by Kuusi (1991):

*In 1999, the fetuses of all pregnant women in Finland who give their consent will be examined for at least three hereditary diseases with new methods, either for a small remuneration or no remuneration at all.*

The topic suggests a generalization based on the new biotechnology. The promising target of the generalization is the prevention of hereditary diseases. The promising techniques may be based for example on genetic mapping and the polymerase chain reaction. The methods are discussed in Appendix 3. It is now nearly sure, that that the topic will not realize in 1999. In 1996, in three cities gene examinations of three fatal or disabling hereditary diseases were made without remuneration to all pregnant women who gave their consent. Though in the Finnish town of Kuopio, 90% of the women had give their consent to the examinations, they were stopped in 1997 for economic and partly ethical reasons.

The main relevant findings made in the study by Kuusi (1991) concerning the topic will be presented below. I will later use the next arguments as illustrations in many connections.

In 1989 - when the study concerning the impacts of new biotechnology was made - there were rather few people in Finland who realized the technical potentials of the new gene technology. There were very few who knew the latest highly relevant generic technology, the polymerase chain reaction (PCR). When the Delphi study began, the Delphi managers did not notice the existence of the PCR. One panellist during the study provided crucial information about the prospects of this revolutionary new technology.

In 1989, institutional safety regulation of gene technology was just beginning in Finland based especially on the principles launched by the European Union. Some panellists informed about the general safety principles proposed by EU. Public discussion concerning values in genetic manipulation was in its initial stage in Finland. One panellist provided the Delphi manager with newsletters from critical consumer organizations in Europe and in the USA. Some panellists argued that the problem of hereditary diseases is more difficult in Finland than in many other countries. The Finnish population has many fatal or disabling hereditary diseases which the people of other nations do not have.

Relevant information concerning the costs of gene diagnostics was received for example from a panellist working in a small firm specializing in restriction enzymes. Information concerning the funding of development projects for gene examination were obtained from panellists working as public health authorities and

from a panelist working in TEKES (Technology Development Centre of Finland). It is the main public organisation for financing technological development in Finland. TEKES had launched a technology program in new biotechnology.

The arguments were obtained both from the first round Delphi interviews, when the topic was not yet specified and as comments to the specified topic in the second mail round of the Delphi study. The most important comments concerning PCR were actually obtained in the third Delphi round, where some specialists were asked to specify their general arguments.

Let us suppose that an opinion poll was made in 1989 concerning the above topic based on the expertise which the Delphi managers had in the beginning of 1989, and let us suppose that this study tried to take into account the scientific principles discussed by Sackman.

The statistical significance and reliability require that the rather large (the minimum is approximately 100; in author's Delphi study 30 persons were on the panel) sample of panellists is selected from a rather large and rather homogenous universe or base group, from which it is possible to take another control sample. In Finland, the number of experts who used in 1989 most advanced techniques of the new biotechnology (e.g. the PCR) was extremely small. It may be, however, that the situation concerning the topic was actually analogous to the study of Bredford (1972) discussed by Sackman (1975,42). Bredford matched a group of twenty-five housewives against a group of twenty-six experts in "communications, consumer behavior, sociology and futurism generally" in a two-round Delphi study on "The Future Communications Services in the Home." Bredford found, using a long and extensively questionnaire, "remarkably few differences between the experts and the housewives on the panel".

Taking into account the crucial role of values concerning the realization of the topic, it is possible that a poll of mothers having small children might have been produced a more predictive valid (and statistically significant and reliable) evaluation concerning the topic than the evaluation of my panel of experts, most of whom belonged to the nucleus of the gene technology developer community.

If the benchmark of a behavioral science is considered to be the discovery of transient invariances and predictions based on them, the poll of the mothers might have been more scientific than my study. If the scientific quality of a future study is based on the epistemology of the general theory of consistency, the situation is more complicated. From that point of view, the epistemic value of transient invariances of actors is rather insignificant. The same concerns even right predictions based on those invariances. Only permanent invariances of not-learning beings are scientifically really interesting. Transient invariances are scientifically interesting as far as they can be used for the identification of real ca-

capacity limits, genuine interests and real capability limits of actors. *The point is that the focus of scientific foresight is not to make outsider predictions based on prejudices of actors but to find what will happen in the future, if relevant actors act reasonably and use their learning capacity as far as possible.*

Let us look at the topic from this point of view. We may compare the results of my study and the hypothetical opinion poll. The comparison can be based on the relevant rational arguments, which my study produced in 1989-1990 and which the hypothetical opinion poll might have produced concerning the discussed topic. In the table 3.1. I will list some relevant arguments (concerning the invariances of unlearning beings and interests, capacity limits and capability limits of actors).

As the list of above arguments shows it is reasonable to suppose that author's study produced more rational arguments than the hypothetical opinion poll. Though author's study did not provide a statistically significant, reliable and validated evaluation of the future realization of the topic, it provided many validated arguments affecting the topic. Evaluation of information values of different arguments is discussed in more detail in the next paragraph.

If the main point of a Delphi study is to produce rational arguments concerning the future topics, and less to make judgments concerning future developments, the critical arguments A - E and H - I of Sackman are not very dangerous. In fact, as far as the finding of relevant arguments is concerned the number of panellists or the number of their answers is rather irrelevant. A case discussed by Sackman (1975,22) is illustrative. In 1973, Arthur D. Little, Inc. made a Delphi study for health authorities to arrive at a consensus on the proper level of exposure to asbestos fibers. The panellists were apparently members of the asbestos manufacturing community. Only one person on the panel was not a paid consultant of some segment of the asbestos industry or whose investigations into asbestos-related disease had not been supported by the asbestos industry. It is clear that in this case the one dissident was in a special position in the production of rational future arguments. It is, however, also important to realize that though this panel was clearly incapable of making any impartial judgments concerning norms for asbestos, even it was in principle capable of producing rational arguments concerning future developments.

*Table 3.1. Arguments related to the topic: In 1999, the fetuses of all pregnant women in Finland who give their consent will be examined for at least three hereditary diseases with new methods, either for a small remuneration or no remuneration at all.*

The notion "the results of the Delphi study are marked "D" and hypothetical results of the opinion research "O". The certified fact" or "CF" is used in the case of an argument which is validated (in addition to any expert evaluation) through a trustworthy source, for example articles in scientific journals. The arguments which are most favorable for the realization of the topic are on the top. The most unfavorable arguments are at the bottom.

1. The problem of hereditary diseases is more difficult in Finland than in many other countries. In addition to the internationally important hereditary diseases, the Finnish population has many fatal or disabling hereditary diseases which other nations do not have, CF (D).
2. There are new powerful technologies e.g. gene sequencing technologies and PCR, which can be used in the diagnosis of hereditary diseases. The genetic codes of many difficult hereditary diseases were in known 1990, e.g. Duchen muscular dystrophy and cystic fibrosis CF (D).
3. If abortion is allowed for economic reasons why not study the reasons for abortion based on difficult hereditary diseases? An opinion of a panelist (D).
4. The costs of the gene examination for three hereditary diseases in 1999 will not be much higher than those of the routine test for Down's syndrome which was made to ten per cents of pregnant women in Finland in 1989. An evaluation of panelists working in relevant biotechnology firms or in public sector biotechnology funding institutes (D).
5. The European Union is preparing general (minimum) ethical guidelines for gene therapy. These guidelines prevent the ethically most questionable applications of gene therapy or diagnostics CF (D).
6. From 20 panellists 75% did not think that the topic would be realized (D).
7. Many panelists considered that there are small technical obstacles to the realization of the topic. They considered, however, that the economic and especially cultural constraints will hinder its realization in 1999 (D).
8. According to a statistically significant and reliable opinion measurement in 1990 81% of the Finnish women with children under three years of age, thought that the topic would not be realized (O).
9. 90% of the sample of mothers considered that cultural or ethical restrictions will be the main reasons for not realizing the topic (O).
10. People should not tamper with the work of God. An opinion of a mother (O).
11. There were movements of people in the EU area (especially in Germany) and in the US which have successfully opposed gene manipulation (D).

The argument M of Sackman is relevant only as far as the disagreement concerning "where we are" is relevant concerning the finding of arguments with an impact on future developments. It is possible to express rational arguments concerning the changes in the present situation without knowing the present situation exactly. On the other hand, especially in the processing of arguments, that did originally not have other sources of validation than the opinion of the panelists, the critical arguments F - G and J - L of Sackman are highly relevant.

Content validity and the connections of the Delphi results with reliable theories (Sackman's points F and G) are related to the scientific or technological paradigms discussed in the previous chapter. The content validity is closely related to the validation methods of technological paradigms. Because there is no entirely reliable way of determining the validity of suggestions concerning the future, arguments which increase the content validity of these suggestions are essential. This conclusion is the important starting point of the epistemic utility model discussed in the next paragraph.

From the point of view of the production of rational arguments, the level of expertise is not the key property of the panel experts. The key property is the panellist's salience in the production of valid and relevant arguments. A top expert typically knows many more valid and relevant arguments than he expresses in a Delphi study and often important arguments are heard from less qualified but salient persons. They are often also "catalysts" who provoke relevant arguments from top experts. The critical arguments J - L of Sackman are closely connected to the question of how to select a group of experts from the developer community of a discussed generic technology which in the Delphi communication process *as a group* is as efficient as possible in the production of arguments.

Many examples of the bad use of Delphi method presented by Sackman concerned social topics. A clear problem of national technology Delphi studies has been the expertise of the panelists in social matters. Because the panels have been selected mostly based on the expertise in technical matters, the panellists may have peculiar views concerning social matters. The problem is indicated by the fact that the demographic structures of the panels have been very biased. In the Sixth technology forecast survey of Japan the share of female panelists was 2% and the respondents under 30 years 1%. (NISTEP 1997), in the United Kingdom study and in the last German study the shares were about 5% and about 1% (Loveridge et al. 1995, Cuhls et al. 1998).

I consider it essential to realize that any technology generalization has a social aspect ("relevancy aspect" in my later discussion) concerning which technical experts are seldom likely to be the best producers of rational arguments. A clear step forward in the above problem was made in the last German technology Delphi study. All panelists give their evaluations concerning nineteen social



"megatrends", e.g. "There will be warlike conflicts between poor and rich countries" (Cuhls et al. 1998, Zusammenfassung, 13). A factor analysis was made concerning their opinions. It is possible to compare how the evaluations of the panelists differ from the evaluations of other groups of people and how this influences technological views.

It is interesting to compare my answer with the critiques of Sackman to that answer which Cuhls (1998) gives to Sackman based on her experiences in Japanese and German national technology Delphi studies. She has been a project coordinator in the comparison of Delphi studies in Japan and Germany (Cuhls and Kuwahara 1994) and in the last German technology Delphi studies (Cuhls et al. 1998, Cuhls et al. 1995).

The total argumentation of Cuhls (1998) is not far from the idea that the focus of a Delphi study should be the production of rational arguments concerning the future. Cuhls considers (p.333) that it is very difficult to evaluate foresight in general and especially, how exact the predictions of a Delphi study are. She refers to the results of Ono and Wedemayer (1994) and concludes that the Delphi predictions can be rather valid. In fact, the predictive validity of the results of Ono and Wademayer is rather questionable, as I will show in paragraph 3.10. The main arguments of Cuhls are, however, the following:

1. Are there available any better sources of information for *longrange* forecasts than the knowledge of experts?
2. It is important to look at self-destroying as well as self-fulfilling prophecies.

Cuhls considers that one of the main tasks of the Delphi method is to hinder the realization of unimportant or undesirable happenings (or technology generalizations). Cuhls considers that a decision not to go further in a certain direction can also be a "success" (although then, the "prediction" is wrong). This is a conclusion which is clearly in line with my point of view. *The role of Delphi experts is to make rational arguments concerning the future making possible more reasonable decisions concerning future.* Even the predictions of the experts can be seen as arguments. I will later call the predictions made by panelists as "proxy-arguments" based on the tacit knowledge of experts.

Cuhls' basic answer to Sackman's critique concerning information about panelists (point K above) is that the basic statistical data of the panelists (sex, age groups and professional activity) have been available in national Delphi studies without violating their anonymity.

It is possible to use statistical background variables for the evaluation if the pooled opinion of experts is better than that of any subgroup of experts by counting correlation between background variables and answers to different top-

ics. Cuhls, however, considers that it is possible to evaluate the validity of predictions only after 30 years or whenever it becomes clear that topics are realized or are not realized.

Though Cuhls' conclusion is true concerning predictions, it is not, however, valid concerning the arguments on which the predictions of future events are based. Experts differ in their saliency and trustfulness in the production of both factual and "proxy" arguments. As I will in detail discuss in Chapter 5, it is vital to realize the specific role of a panelist in the developer community of a technological paradigm or in some fields of topics using the analogous concept of Cuhls. Beside roles in the developer community, psychological dimensions such as optimism-pessimism are also important (compare Cuhls 1998,334) concerning the salience and trustfulness of arguments.

Cuhls considers that the critique of Sackman concerning the vagueness of topics is justified to a certain extent. She considers that the unequivocality of topics should be stressed more. I consider, as in fact does Cuhls when she discusses the role of topics as general targets, that in an argumentation process concerning the topics, vague formulations have also advantages. They provoke factual arguments as explanations.

A common feature of the most vehement critics of the Delphi method is that they have considered this method - or at least the traditional Delphi method, on which most of their critique is focused - as a prediction method which even hinders the production of genuine arguments. Sackman (1975, 54) expressed it as follows:

Delphi deliberately factors out face-to-face confrontation, and the adversary process associated with it, as one of its prime philosophical tenets justifying efficient consensus. Arguments are filtered, buffered and effectively neutralized in Delphi. A panelist can participate without providing any justification for any of his opinions throughout the entire procedure. More conscientious panelists provide occasional brief commentaries.

And further (p. 64):

A fundamental epistemological confusion exists between Delphi method and Delphi results. Practitioners claim that the end result of a Delphi study is a series of expert forecasts of future events... Delphi forecasts are opinions about such broad classes of events, not systematic, documented predictions of such events.

Woudenberg (1991,132) defined the starting points of his Delphi critique as follows:

Based on the above-mentioned literature reviews and expectations derived from them, the different judgment methods can be put on a scale of increasing accuracy. In this article the expected high relative accuracy of Delphi is evaluated.

Woudenberg evaluated the accuracy of the Delphi method by laboratory experiments, in which practically no factual arguments were presented. He did not find any systematic differences between the accuracy of different judgment methods: Delphi; staticized group ("usual opinion poll"); unstructured, direct interaction; and structured, direct interaction (e.g. "nominal group method"). The main conclusion of Woudenberg (1991, 39) was "that factors other than the specific method used (capability of the group leader, motivation of the participants, quality of instructions, etc.) to a large extent determine the accuracy of an application of a judgment method".

But did Woudenberg seek an answer to the wrong question? If the accuracy of predictions or evaluations is not the main criterion of a successful Delphi study, what should it be? That is the topic of the next paragraph.

### **3.4 A Model for the Epistemic Value of Technology Foresight Delphi Study Arguments**

Some technical features of the traditional Delphi method have obscured the original idea of the Delphi method. These technical features have in the hands of uncritical practitioners, resulted in applications of the Delphi method which deserve the hard critique of Sackman (1975) and Woudenberg (1991). If the practitioners of the method had looked instead of mechanically following the technical rules more closely at the purpose for which the technical procedures were constructed there would not be so many bad applications of the method.

The original idea of the Delphi method was to make well-argued judgments. This is actually the same target, that most expert working groups or committees have. In this paragraph, I will discuss what implications can be made from this general idea for the success criteria of technology foresight with the Delphi methodology. In the next paragraph, I will evaluate the technical features and process stages of the method against the success criteria.

A special point which I would like to emphasize strongly is that the Delphi method is not best at finding accurate judgments concerning future events but at revealing valid and relevant arguments for the judgments. What really happens in the future is typically not based only on valid arguments. The epistemic mistake which confuses rational arguments and judgments with actual happenings, has

very much confused the discussion about the Delphi method and hindered its development.

In this paragraph, I will present a model for evaluating epistemic value of technology Delphi argumentation. The model is based on a special interpretation of rational behavior. The background of the model is the epistemology of the general theory of consistency (GTC) (originally Kuusi 1974) discussed in the first chapter. I will start, however, the discussion about the model with comparisons with the traditional economic concept of rationality and the ideas of bounded rationality discussed by March and Simon (1958) and Eliasson (1996).

### 3.4.1 Features of rational arguments

The traditional rational man of economics and statistical decision theory makes "optimal" choices in a highly specified and clearly defined environment (March and Simon 1958, 137-138):

1. In front of the decision-maker is the whole set of alternatives, from which he will choose his action.
2. To each alternative a set of consequences is attached - the events that will ensue if that particular alternative is chosen. The existing theories fall into three categories: a) *Certainty*: theories that assume the decision-maker has complete and accurate knowledge of the consequences that will follow on each alternative. b) *Risk*: theories that assume accurate knowledge of a probability distribution of the consequences of each alternative. c) *Uncertainty*: theories that assume that the consequences of each alternative belong to some subset of all possible consequences, but that the decision maker cannot assign definite probabilities to the occurrence of particular consequences.
3. At the outset, the decision-maker has a "utility function" or a "preference-ordering" that ranks all sets of consequences from the most preferred to the least preferred.
4. The decision maker selects the alternative leading to the preferred set of consequences. In the case of certainty, the choice is unambiguous. In the case of risk, rationality is usually defined as the choice of that alternative for which the expected utility is greatest. In the case of uncertainty, the definition of rationality becomes problematic. Possible strategies are e.g. maxmin or maxmax strategies.

As March and Simon (1958,138) remarked, there are difficulties with this model of rational man. Even if we accept the calculation with probabilities as rational, the model makes three exceedingly important demands upon the choice-making

mechanism. It assumes 1) that all the alternatives of choice are "given"; 2) that all the consequences attached to each alternative are known at least as probabilities 3) that the rational man has a complete utility ordering for all possible sets of consequences.

In what sense can we speak about rational choice if the above assumptions are not met or if only bounded rationality - using the concept of March and Simon - is possible? *My suggestion is that reasonable or bounded rational choices can be based on rational arguments.* In order to make reasonable choices, rational arguments are used to produce a special type of utility which I call "epistemic utility" even in a situation where not all the alternatives, consequences and utilities connected with the consequences are not known.

Behind my concept of epistemic utility is a kind of learning process. It is supposed that a decision-maker first makes a "first guess" epistemic utility value of any relevant technology generalization option. The first guess is based on many types of arguments perceived by the decision maker. In the beginning of the learning process the arguments are very much part of his or her tacit knowledge. They concern the technical feasibility of the option, the impacts on "objective" targets, the relevancy of the impacts or consequences of realizing the option. The arguments can include objective probabilities, which the decision-maker knows, or they might be based on his or her subjective intuitive probabilities.

The second main phase is an argumentation process transforms tacit arguments explicit. It results in the production of new arguments, which contribute to the epistemic utility of the evaluated option. The decision-makers - or independent observers - make also an evaluation of the validity or the rationality of arguments behind the epistemic utility evaluation.

The final stage is the decision to continue or not to continue the realization of the technological option. This means a further allocation of resources to its realization. An important aspect of this choice is the minimum acceptable level of validity of the option. In practical decision making the trade-off between the traditional utility value of an option and the validity of the utility evaluation of the option is rather evident. It can be seen to be behind this minmax decision rule: consider the worst set of consequences that may follow from each alternative, then select the alternative whose "worst set of consequences" is preferred to the worst sets attached to other alternatives. Let us suppose that A is the best alternative based on the minmax rule. Let us suppose that there is another alternative B having a possible set of consequences which are in general clearly better than the possible consequences of A exempt the worst set of consequences ( $\min A > \min B$ ). If the decision maker in this situation selects A she is ready to "sell validity paying an utility price". Her decision is based on a valid argument "I will get at

least min A" instead of an invalid but reasonable argument "It seems that I will get more with B".

The "epistemic utility" concept was firstly used by Carl G. Hempel and Isaac Levi in the early 1960s (Niiniluoto 1987, 406). They suggested that acceptance of scientific hypotheses could be based upon the rule of maximizing "epistemic utilities". In contrast with various kinds of "practical" benefits, the epistemic utilities should reflect the cognitive aims of scientific inquiry. Levi has argued that the scientist's task of "replacing doubt by belief" should aim at least to true belief, and could be "tempered by other desiderata such as simplicity, explanatory power, etc." These objectives of autonomous scientific inquiry are "quite distinct from those of economic, political, moral, etc. deliberation" (Levi 1967, Niiniluoto 1987, 410).

From the point of view of the epistemology of the GTC a reasonable interpretation of Levi's program is that the epistemic utility measures the distance between perceived and true criteria of sameness of a not-learning being. The criteria of sameness of a not-learning being are, however, always interpreted through a language of some learning being (or of an actor). Because the development of languages of learning beings are related to their interests, it is not possible to define the simplicity or explanatory power of a theory concerning invariant criteria of a not-learning being without taking into account the interests of the learning being. This means that we cannot build a relevant concept of epistemic utility without target/actor related considerations.

Though my concept of "epistemic utility" depends on economic and moral deliberation (the relevancy aspect), it has an important common feature with the original idea of Levi. My model of epistemic utility (which I will present soon) is based on the idea, that if an argument increases the validity of a specified option, the epistemic utility has to increase. The epistemic utility has to increase even in a case, in which the argument implies the deterioration of impact, feasibility or relevancy values of the option. We might suppose that the measure of validity of rational arguments might be based just on a kind of epistemic utility suggested by Levi and discussed by Niiniluoto (1987).

It seems to be easy to accept a hypothesis, that a decision-maker prefers a technology generalization option with well validated consequences to the same technology generalization option with poorly validated consequences. This is, however, a stringent requirement, which is evidently not often met in actual behavior. If a validation process worsens the consequences of a technology generalization option, decision makers are often very reluctant to accept the bad news. They might reject or try to forget evidently valid arguments in order to sustain their position as experts. They consider - often rightly - that the increase of epistemic utility is in contradiction with their interests (or their traditional expected utility)

and for example they wishfully hope that some new information would nullify the bad news or they try to hinder other actors to get the bad news. This is a main reason for the fact that the human decision making is seldom epistemic rational in a strict sense.

In any case, for a rational decision-maker the low level of the validity of argumentation is the reason for a search process for new relevant arguments. The difference between rational and irrational arguments can be based on their impacts on the epistemic utility. Any new rational argument improving the total validity of argumentation should have a positive impact on the epistemic utility of a future generalization of technology. On the contrary, an approved irrational argument, which has a negative impact on the general validity of argumentation, should have a zero or worsening effect on the epistemic utility.

The validity aspect of the epistemic rationality is a counterpart of the cognitive rationality of Resher (1995). He considered that rationality may be evaluative or pragmatic in addition to cognitive ("rejecting untruths or presenting truths"). In ignoring evaluative rationality the risk is to endorse inferior items (in GTC "to select items which do not belong to capability limits") and in ignoring practical rationality the risk concerns the failing to achieve appropriate ends (in GTC "the realization does not belong to capacity limits"). My point is that Resher's three types of rationality (or reasonability) may be in contradiction with each others in the short run. My epistemic utility model suggests that in that situation the cognitive reasonability should have the first priority because it is decisive in the long run.

Epistemic rational arguments have some formal features. John Woods and Douglas Walton (1982) have suggested as a minimal requirement for a comment to be an argument that it should have the logical form of an argument. It has to be a set of propositions: one is called the conclusion, the others premises. In practical argumentation, a problem is that some or sometimes even all premises are implicit. Rational argumentation requires that important implicit premises are made explicit if they are not evident without such an explication.

Karl Popper has suggested another formal feature for rational argumentation. According to him, a minimum requirement for rational discussion concerning the empirical validity of an argument is that there is at least some condition of world which can refute the argument. This idea which is the cornerstone of 'critical realism', seems also to be essential for evaluation of the rationality of value judgments, as we already discussed in the first chapter.

Habermas (1995, 15) connects rationality with the consistency like the GTC. According to him we may also call someone rational if he or she makes known a desire or an intention, expresses a feeling or a mood, shares a secret, confesses a

deed, etc., and is then able to reassure critics in regard to revealed experience by drawing practical consequences from it and behaving consistently thereafter. A problem in the standpoint of Habermas is the above mentioned rejection of evidently valid arguments concerning invariances or the capacity or capability limits of other actors. If "reassure critics" means rejecting validated evidence, we are no longer in the sphere of epistemic reasonable behavior though the behavior might be motivated from the point of view of traditional utility based reasonability.

### **3.4.2 Evaluation criteria of the epistemic utility of technology generalization options**

In the next subparagraph, I will present a simple mathematical model for the evaluation of the epistemic utility of technology generalizations. In this paragraph I will illustrate the evaluation criteria used based on the arguments presented in the study of Kuusi (1991). Let us once again look at the generalization of new biotechnology discussed above and by Kuusi (1991):

*In 1999, the fetuses of all pregnant women in Finland who give their consent will be examined for at least three hereditary diseases with new methods, either for a small remuneration or no remuneration at all.*

What kinds of epistemic rational arguments can be found concerning this topic? The first group of arguments concerns the concrete or objective targets, the attainment of which can be evaluated without disagreement. They define potentially important *impacts* which the new methods or technology generalizations may have. My study produced e.g. the following argument belonging to this group (the numbers refer to the list on the paragraph 3.3.):

1. The problem of hereditary diseases is more difficult in Finland than in many other countries. In addition to the internationally important hereditary diseases, the Finnish population has many fatal or disabling hereditary diseases which other nations do not have.

If a technology results in the avoidance of a hereditary disease, we can suppose, that this impact can be noticed without disagreement. A second group of arguments are focused on the *feasibility* of the techniques in achieving of impacts. Following arguments belonged to this group:

2. There are new powerful technologies e.g. gene sequencing technologies and PCR, which can be used in the diagnosis of hereditary diseases. The genetic codes of many difficult hereditary diseases were in known 1990, e.g. Duchen muscular dystrophy and cystic fibrosis.



4. The costs of the gene examination for three hereditary diseases in 1999 will not be much higher than those of the routine test for Down's syndrome which was made to ten per cents of pregnant women in Finland in 1989.

What kinds of arguments have impacts on the *validity* of argumentation? I already discussed the problem of validity on a general level above. The validity of a technology generalization proposal is related to the following question: is the suggested technique really able to produce the suggested impacts on suggested conditions (for example using the suggested resources)? The validation is based on a validation method. For example the validity of an opinion poll might require that the documentation should clearly indicate, what universe is represented and how adequate is the sampling. Though it might be possible to proceed in the development of an objective or general validation method (e.g. based on the "epistemic utility" of Levi or Niiniluoto (1987)), proper validation methods depend on the languages of actors. As I have discussed earlier, these paradigm-based inductive or deductive inferences are actually generalizations based on criteria of sameness:

The inductive inference :

The validity of a generalization proposal  $a_2$  which is not yet realized increases because a similar generalization  $a_1$  is realized.

The deductive inference:

A generalization proposal is more valid because it belongs to a similarity group of valid generalizations.

For example in the Darwinian paradigm, the finding of a fossil ( $a_1$ ) which does not resemble the present species supports the assumption that there was once that type of species ( $a_2$ ). In the pre-Darwinian paradigm  $a_1$  is only a caprice of nature without further implications concerning  $a_2$ .

Let us suppose that somebody suggests that a technique can produce specified impacts in specified conditions and assesses the validity of the suggestion based on some validation method. The *relevancy* of the suggestion differs for different actors. I use this concept to describe all aspects of decision-making which depend on the "special mental map" of an actor. The actor may first have a different validation method for the suggestion. Second, actors assign different values to the impacts proposed (impacts are supposed to be perceived in the similar way by all actors). A person may e.g. consider that he has a minimal risk of taking responsibility for a child with a hereditary disease. Different impacts are relevant to him

than to a person with a great risk of having such a child. Third, the proposed technology generalization may produce impacts which are not mentioned in the suggestion and which the actor considers to be relevant. The relevancy evaluations might be systematic as in the European Union as was realized by an argument presented in Kuusi (1991):

5. The European Union is preparing general (minimum) ethical guidelines for gene therapy. These guidelines prevent the ethically most questionable applications of gene therapy or diagnostics.

Unlike the means-ends model discussed in the chapter 1, I consider that there might be rational arguments related to relevancy evaluations. There might be epistemic rational arguments concerning the reasonability of "mental maps" of actors. Another possibility is to present true transient invariances concerning the relevancy evaluations of some actors. The first three arguments concern real or potential mental maps. The last argument refers to a (hypothetical) transient invariance:

3. If abortion is allowed for economic reasons why not study the reasons for abortion based on difficult hereditary diseases?

7. Many panelists considered that there are small technical obstacles to the realization of the topic. They considered, however, that the economic and especially cultural constraints will hinder its realization in 1999.

11. There were movements of people in the EU area (especially in Germany) and in the US which have successfully opposed gene manipulation.

8. According to a statistically significant and reliable opinion measurement in 1990 81% of the Finnish women with children under three years of age, thought that the topic would not be realized.

### 3.4.3 A model for an action-inducing epistemic utility of argumentation

The idea behind the next model is a convenient situation in technology foresight studies. A topic in a study suggests that specified impacts ( $i_1, i_2, \dots, i_n$ ) are achieved now or later using some specific technique. For example, somebody may suggest that different hereditary diseases in fetuses of pregnant women will be monitored in 2010 using a specific technique. My idea is to formalize the contributions of different arguments for rational evaluation of this kind of technology generalization suggestion.

Let us suppose that we are making a study concerning the future technology generalizations based on a technological paradigm of new biotechnology. What is the value of a single argument in this kind of argumentation process? The value of the argument can be assessed according to its contribution to the total value of argumentation. I describe this total epistemic value of an argument related to a technology generalization with "epistemic utility". The idea is that if the epistemic utility of a generalization increases, it is from the epistemic or cognitive point of view more reasonable to start a realization process of the technology generalization. We can describe the contribution of a single argument A to the total epistemic utility value  $U_{ik}$  of a technology generalization  $i$  to an actor  $k$  as follows:

$$U_{kiA} = U_{ik}(I_i^1, F_i^1, V_i^1, R_{ik}^1, L_k) - U_{ik}(I_i^0, F_i^0, V_i^0, R_{ik}^0, L_k)$$

In the formula

- $I_i^0$  and  $I_i^1$  describe suggested (objective) impacts of the generalization  $i$  on proposed targets before and after the presentation of the argument A;
- $F_i^0$  and  $F_i^1$  are the suggested before and after feasibility values of used technique(s) of  $i$  used in the producing of the impacts;
- $V_i^0$  and  $V_i^1$  are values of validity of the generalization  $i$  before and after the presentation of the argument A (does the proposed techniques really produce the proposed impacts based on a suggested validation method);
- $R_{ik}^0$  and  $R_{ik}^1$  are the before and after relevancy of the generalization  $i$  to the actor  $k$ ; (including  $k$ 's evaluation of the suggested validation method) and
- $L_k$  is the minimum value of action inducing suggestion from the epistemic point of view for the actor  $k$ .  $L_k$  can be interpreted to be the opportunity cost of the most reasonable alternative technological option.

It is assumed that all actors (or experts in a Delphi study) interpret in the same way the suggested impacts (I), the suggested feasibility (F) and the suggested va-

lidity (V). This means that these values do not depend on the actor k. The possible doubts concerning e.g. unnoticed impacts or the correctness of the suggested validation method are visible in the actor dependent value of the relevancy (R). It is assumed that  $L_k$  does not depend on the discussed argument. In reality it might, however, have a contribution to the opportunity costs of the discussed option.

What do we know about the function  $U_{ik}(I_i, F_i, V_i, R_{ik}, L_k)$ ? The epistemic utility function  $U_{ik}$  of the generalization i to the actor k is an increasing function of  $I_i, F_i, V_i$  and  $R_{ik}$ . Another property is that if  $I_i, F_i, V_i$  or  $R_{ik}$  is zero,  $U_{ik}$  is zero. If we consider that a change in epistemic utility has to be relevant for action,  $I_i, F_i, V_i$  and  $R_{ik}$  should have such high values that the starting of the realization process of the technology generalization i can be reasonable now or later. This minimum reasonability level is described by  $L_k$ . From the role of  $L_k$ , it follows that  $U_{ik}$  is a decreasing function of  $L_k$ . A simple mathematical function which meets all above requirements is given below for  $U_{ik}$  or for the total epistemic utility value of the generalization i to the actor k :

$$U_{ik} = \text{Max}(I_i F_i V_i R_{ik} - L_k, 0)$$

The “Max” means that  $U_{ik} = 0$  if  $I_i F_i V_i R_{ik} - L_k < 0$ . This is a reasonable assumption, because knowledge concerning a technology generalization can never have a negative impact on the epistemic utility of a reasonable actor. The possible positive impacts are discussed below. In fact, the monitoring of irrelevant alternatives may have also negative effects because it may hinder the monitoring of relevant alternatives.

We obtain a more simple and perhaps in some connections more practical formula for the total epistemic utility value of an argument in a technology foresight study concerning a technology generalization if we look at the newness (or surprise value) of the argument to an actor. Using a newness indicator, the value of a argument A concerning a technology generalization i to the actor k is

$$U_{kiA} = \text{Max}(I_i^1 F_i^1 V_i^1 R_{ik}^1 - L_k, 0) N_{ik} = \text{Max}(I_i^1 F_i^1 V_i^1 R_{ik}^1 - L_k, 0) - \text{Max}(I_i^0 F_i^0 V_i^0 R_{ik}^0 - L_k, 0)$$

$$\text{or if } \text{Max}(I_i^1 F_i^1 V_i^1 R_{ik}^1 - L_k, 0) > 0$$

$$N_{ik} = 1 - \text{Max}(I_i^0 F_i^0 V_i^0 R_{ik}^0 - L_k, 0) / \text{Max}(I_i^1 F_i^1 V_i^1 R_{ik}^1 - L_k, 0)$$

where  $N_{ik}$  is the newness of the argumentation concerning generalization  $i$  to the actor  $k$ .

We can see from the formula that if the argumentation process does not improve the epistemic utility or  $\text{Max}(I^1_i, F^1_i, V^1_i, R^1_{ik} - L_k, 0) = \text{Max}(I^0_i, F^0_i, V^0_i, R^0_{ik} - L_k, 0)$ , the newness value is 0.

As I mentioned above, the difference between traditional economic utility concept and my epistemic utility is based on the special role of validity. I define below this special role only concerning reasonable technology generalization proposals with defined  $I$ ,  $F$ ,  $R$  and  $V$ . In order to express my idea clearly, I have firstly to define five auxiliary concepts: reasonable technology generalization proposal from the epistemic point of view, reasonable relevancy evaluation, close target/impact horizon, close technique horizon and tested preference values.

I define a *reasonable technology generalization proposal from the epistemic point of view* in the following way: technique(s) is (are) suggested to produce specified impacts with a specified feasibility (e.g. the use of resources) and the level of validity of the suggestion is implicitly or explicitly evaluated based on a specified validation method.

A *reasonable relevancy evaluation* of a reasonable technology generalization proposal is based on four basic reasons:

- the proposed techniques may produce impacts which are not mentioned in the suggestion and which the actor considers to be relevant (targets inside a close target/impact horizon, see below);
- there are close techniques not mentioned in the suggestion (techniques inside a close technique horizon, see below);
- actors may have different validation methods concerning the relationships between discussed techniques and impacts (different validation paradigms); and
- the preference values are tested (see below) related to the proposed and close impacts;

With the *close target/impact horizon* I refer to those targets/impacts which necessarily are related to the production of the suggested impacts using the suggested techniques. E.g. a medicine might have negative side effects. The target horizon of a technological paradigm is typically very much wider than the close horizon.

With the *close technique horizon* I refer to those complementary techniques needed beside the suggested techniques to produce discussed impacts. The technique horizon of a technological paradigm is typically very much wider than the close horizon.

With *tested preference values* I refer to the four criteria of Keekok Lee's epistemic implication model (Lee 1985) and my criterion of not-contradictory criteria of the sameness discussed in the first chapter. The preference values have been tested based on:

- Serious refutable evidence
- Referentially relevant evidence
- Causally relevant evidence
- Causal independence
- Not-contradictory criteria of the sameness of an actor.

***Special Assumption concerning the Relationship between Indicators of Impacts, Feasibility, Validity and Relevancy:***

Let us assume that actors accept a common validation method. Let us suppose also that we have a reasonable technology generalization proposal based on that validation method. In that case the relationships between indicators of I, F, R and V related to the proposal are defined so that every argument having a positive impact on V has also a positive impact on the total epistemic utility value of the technology generalization proposal.

The assumption that actors should have a common validation method is restrictive. It means either that there is an "universal" validation method or actors have rather close scientific paradigms. The assumption is made in order to make the special assumption simple. More modest and perhaps more reasonable assumption could be that validity has to increase in any used validation method.

If the problem concerning the common validation method is not too serious, we might suppose that the measures of I, F and R are in such a relationship with the measure of V that the net epistemic value of rational argumentation is positive also in the case, where a validity improving argument impairs the value of  $I_i \times F_i \times R_i$ . This means that the value of  $V_i$  has to rise at least as much as  $I_i \times F_i \times R_i$  decreases.

I illustrate this relationship with a case which I will discuss more closely in the chapter 7. PKU is a hereditary disease which if left untreated leads to severe mental retardation. There is a fetus test which yields false positives. Let us suppose that the wrong diagnosis happens in ten per cent of the cases (the feasibility is 0,9). Let us suppose that somebody suggests that the technique always gives the right diagnosis (the feasibility is 1,0). We have to decrease the validity of the argumentation by more than ten per cent, because it is evidently better to have the right feasibility value.

Presently, the special assumption is more a kind of ideal than a specified criterion. I already mentioned that the principle "bad news might be good epistemic news" is often a stumbling block of the epistemic reasonable argumentation. From the point of view of some other type of reasonability than the epistemic reasonability it is often reasonable to forget or hide bad news, which are good epistemic news.

An argument, that impairs the epistemic utility or which has a negative newness value can be irrational or "semirational". It is possible that there are "semirational" arguments or "bad news" which have no impact on  $V$  but impair the value of  $I$ ,  $F$  or  $R$ . A rational decision maker does not approve such a semirational argument. The same of course concerns every argument impairing the value of  $V$ .

March and Simon (1958, 140) called an alternative satisfactory if (1) there exists a set of criteria that describes minimally satisfactory alternatives, and (2) the alternative in question meets or exceeds all these criteria. My model suggests that the actor  $k$ , who likes to maximize the use of valid arguments in her decision-making, starts a realization process of a technology generalization, if the generalization proposal meets the criteria of a minimally satisfactory option. It has to be good enough in all relevant targets; in the feasibility of the suggested and close techniques to achieve the relevant targets; in the importance of the relevant targets; and especially in the validity of the arguments which connect the proposed technique(s) and the relevant targets.

According to March and Simon (1958, 141) in making choices that meet satisfactory standards, the standards themselves are part of the definition of the situation. My standards  $I$ ,  $F$ ,  $V$ ,  $R$  and  $L$  are "metastandards" which have different interpretations in different situations. As March and Simon have stressed, in practice standards are raised whenever alternatives (good enough technology generalizations) proved easy to discover, and lowered whenever they were difficult to discover. In the case of my metastandards, this is possible by changing the value of  $L_k$ .

### 3.4.4 Epistemic utility and the general epistemic value

My measure of epistemic utility is constructed for decision-making, which tries to maximize the use of valid arguments. An argument may have "general epistemic value" besides action-inducing value. An argument may expose a new validated invariant relationship between a target and a technique, but the target may be so unimportant that the use of the technique does not meet the minimum epistemic utility level for its use. In that case, the argument telling the validated in-

variant relationship between the target and the technique produces no epistemic utility.

We may consider that the "general epistemic value" (the epistemic utility discussed by Levi and Niiniluoto (1987), which is unrelated to economic utility) produced by the realization of a technology generalization is an impact in addition to other impacts of technology generalization options. We may also, however, assume that in the case of two technology generalizations which are equal in their epistemic utility, the "general epistemic value" indicated by the validity  $V$  decides their order. Especially if the argumentation is evaluated to have a zero value because of low  $R$  value, one can consider that the role of the "general epistemic value" is important. It often happens that the first products using a new technique are unimportant on the market. These products indicate, however, that the technique may be also feasible in the making of relevant products.

### **3.5 An Operationalization of the Epistemic Utility: Microeconomic Interpretation of the Epistemic Utility Model**

The basic microeconomic theory (e.g. Baumol 1951, Malinvaud 1985, Kreps 1990) provides a simple interpretation for the elements of my epistemic utility model with the exception of one important element. The standard theory does not discuss the problem of validity. The final decision concerning realization of a technology generalization is based on the expected future returns to the firm from investment in the generalization. In the realized projects the return of capital has to be higher than a limit value (in my model  $L$ ). The evaluation of the feasibility and impacts (in my model  $F$  and  $I$ ) of a technology generalization are based on the capacity limits using the concepts of the GTC (and not on capabilities, as in the citation below) (Kreps 1990,234):

The standard general model is set as usual in a world where there are  $K$  commodities. Some of these commodities may be inputs to the firm, some may be outputs of the firm, and some may be either inputs or outputs. Still others may have nothing at all to do with the firm. The firm's productive capabilities (capacity limits!) are modeled by a set of netput vectors in  $R^K$ . The term "netput" is used as a generalization of input and output. For each commodity, we record the firm's production or usage of this commodity, using negative numbers for net inputs and positive numbers for net outputs.

The capacity limits define the production possibility set or the technology set for the firm (Kreps 1990,234). Elements belonging to the capacity limits of the firm are called feasible production plans. If the realization of a production plan is based on the generalization of the discussed technology, it is simply assumed that



the  $I \times F$  value of this technology generalization  $g$  can be described by the produced and used netputs ( $q_1, q_2, \dots, q_K$ ). E. g. if  $q_1$  describes the amount of produced insulin (a positive netput or output) we may suppose that with the same negative netputs or inputs (e.g. labor force) the generalization of the gene technology produces a larger  $q_1$  than possible with traditional methods.

"The impact aspect" in a production plan comprises the high levels of outputs produced and the low levels of inputs used. The strictly objective measurement of the "the impact aspect" requires that it is not connected with subjective elements like prices. In practice, a less dogmatic interpretation is, however, often reasonable. From the point of view of a single producer or customer, the market prices and market interest rates may be so "objective" that arguments concerning the relevancy component can often be reduced to arguments concerning the personal relevancy evaluations of market prices, interest rates and amounts produced. The actor evaluates how relevantly the anticipated market value of a technology generalization describes its future value to her.

The arguments related to the "the feasibility aspect" motivate the judgment that it is really possible with available resources (inputs) to produce the planned outputs. The question of validity, which is not discussed in the standard microeconomic analysis, concerns the question of how sure we can be that a production plan can be realized with the proposed technology generalization.

With the above reservations, the prices, the discount ratio and interest rates in the standard microeconomic analysis can be seen as indicators of the relevancy. Every netput has a price. The price which an actor  $k$  is ready to pay for a netput  $i$  describes how relevant this netput is for her. If the outputs are produced and inputs are used in a period 0, which is so short that the time preference or the discount factor can be passed over, the proxy indicator of the total value of a generalization  $g$  is its monetary value  $P_0 = I_g F_g R_{gk} = \sum_i p_{ikg} q_{ig}$  where  $p_{ikg}$  is the (relevancy) price of netput  $i$  for actor  $k$  in the production plan  $g$  and  $q_{ig}$  the net amount of netput  $i$  produced or used. An important point is, however, that  $\sum_i p_{ikg} q_{ig}$  does not give the validity of evaluation concerning the monetary value  $P_0$ . If we do not assume that we are completely informed we have to multiply  $P_0$  with  $V_g$ .

According to the standard microeconomic theory, the rational firm selects a production that maximizes its total discounted profit subject to its technical constraint. It implies that marginal rates of substitution of netputs are equal respectively to the ratios of discounted prices. In particular, the technical interest rates are equal to market interest rates (Malinvaud 1985, 274). Let  $D = 1/(1+i)$  be the discount ratio, where  $i$  is the market interest rate, which is supposed to be the

same in all relevant periods. Let  $P_0, \dots, P_n$  describe the monetary values which are the highest possible with the use of technology generalization  $g$  in the periods  $1, \dots, n$  (i.e. marginal rates of substitution of netputs are equal respectively to the ratios of discounted prices). The traditional (economic) utility value of  $g$  is  $P_0 + DP_1 + \dots + D^n P_n$ . An economic proxy indicator of the epistemic utility of  $g$  to the actor  $k$  is

$$U_{gk}^1(I_g, F_g, V_g, R_{gk}, L_k) = \text{Max}((P_0 + DP_1 + \dots + D^n P_n) V_g - L_k, 0)$$

where  $L_k$  is the minimum level of the expected value required for the realization of  $g$ ,  $V_g$  the validity of argumentation after the argumentation process, and  $U_{gk}^1$  refers to the epistemic utility after the argumentation process. The newness aspect of the technology generalization argumentation can be stated by comparing the value of  $U_{gk}^1$  with the similar value before the argumentation  $U_{gk}^0$ . As in my formula the newness value can be stated in the following way:  $U_{gk} = U_{gk}^1 - U_{gk}^0$ .

There are evidently many everyday technology generalizations in which the above proxy indicator of epistemic utility or the "objective" cost-benefit analysis based on given technologies, market prices and market interest rates is reasonable. This conceptual framework works rather well when the actor is a price taker and when the relevant outputs / inputs are evident. The risk concerning changes in future prices is described using the validity index  $V_g$ . The basic assumption concerning the role of the validity<sup>1</sup> in the epistemic utility is also economically reasonable at least if an argument impairing the expected economic utility of the generalization  $g$  provides the true future prices of the netputs. The proxy measure of epistemic utility is reasonable e.g. in the following technology generalization decision:

When a homeowner replaces his windows, will he use triple glazing?

The narrow conditions of reasonability (or rationality) of the validity extended microeconomic analysis do not function in the case of emerging technology generalizations because the set of possible netputs is not fixed. In the new technology generalizations there is only a vague idea about relevant outputs / inputs and stable price and cost information is lacking. In the present era of rapid technological change, this type of decision situation is more the rule than the exemption.

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<sup>1</sup> The epistemic utility is an increasing function of validity of the argumentation.

A recent comment of the two experts who had earlier used "objective" cost-benefit analysis is illustrative (Linstone and Mitroff 1994,xx):

We still may wax nostalgic when we remind ourselves of the beautiful, elegant, and satisfying results achieved with the paradigms of science and engineering with which we grew up. But we must now face complex systems where everything interacts with everything, where human and technical factors must both be fully appreciated and ethics means much more than logic and scientific rationality.

I disagree with the opinions of the above experts, if they consider that reasonable decision making based on rational arguments is also impossible. I consider that reasonability should be the central focus of technology foresight studies, but that the content of reasonability has to be greatly enlarged from the conception of the rationality of the standard microeconomic theory. The reasonability must include considerations of the commitment of relevant actors which may seem to be irrational from the point of view of the narrow concept of rationality as Linstone and Mitroff (1994, xix) have remarked:

For example, there may be good reasons to do things that appear not to be cost-effective. A company may undertake a research and development program to keep its superb engineering team together, knowing that it cannot make a profit on the project.

My model of the epistemic value of the argumentation concerning generalizations of technologies does not restrict the measurement of I, F, V, R and L to the narrow concepts of the standard microeconomic theory though the microeconomic interpretation of my model is possible. The framework of the standard microeconomic theory is in any case also useful for the analysis of complex technology generalizations because it provides a framework for further questions concerning the importance, feasibility, validity, relevancy and the minimum realization limit of a technology generalization.

Further questions concerning the importance (I) of a technology generalization g are for example:

- 1) What kinds and amounts of products or other outputs are possible based on g?*
- 2) How is it possible to reduce the use of valuable inputs based on g or in more general terms how can g avoid the pitfalls of earlier technologies without creating new ones?*
- 3) If a production plan based on g is realized, are all the relevant "objective" netputs taken into account?*
- 4) On which indicators (e.g. on market prices and on market interest rates) can the "objective" evaluations of the expected market values of netputs be based?*

Further questions concerning the feasibility (F) of a technology generalization  $g$  include:

*5) How is it technically possible to use  $g$  to produce some specific outputs using some specific inputs?*

*6) Will the relevant technology generalization organizations have enough equipment, skilled labor force, monetary resources and networks with important stakeholders or other relevant netputs for a successful generalization  $g$ ?*

The following is a further question concerning the validity of a technology generalization:

*7) How valid are the arguments on which the judgments concerning the above six questions are based?*

Further questions concerning the relevancy of a technology generalization  $g$  to an actor  $k$  include

*8) Are the "objective" market prices of netputs and market interest rates relevant or unbiased measures of the value of  $g$  to the actor  $k$ ?*

*9) Are there some relevant subjective netputs which the actor  $k$  connects to  $g$  but which are not noticed in the "objective" measures of the importance and feasibility of  $g$ ? Are there e.g. international, governmental, organizational or personal (e.g. ethical) restrictions for the production or for the use of some netputs or for the use of some techniques which can connect some inputs and outputs?*

*10) Does the actor  $k$  accept the validity evaluations?*

A further question about how the realization limit  $L_k$  of a technology generalization  $g$  is stated can be formulated as follows:

*11) What are reasonable technological choices taking into account other technological options. Which technology generalizations or production plans can at the same time belong to the capacity and the capability limits of  $k$ ? How can plans, the realization decisions of which actor  $k$  will not have to regret, be chosen?*

The last question builds an important final link to the concepts of the GTC. We may describe the rational argumentation process concerning a technology generalization as a process, that moves from perceived capacity limits (production sets) towards real capability limits (to the realization of reasonable plans).

### 3.6 Basic Types of Factual Arguments Improving Epistemic Utility

The traditional micro economic analysis is rather incapable to evaluate and anticipate the impacts of innovations based on generic technologies, even if the validity aspect of arguments concerning futures is taken into account. I consider that the research tradition of technology foresight studies and especially technology Delphi studies has been much more successful. A main purpose of my epistemic utility model is to give a framework for improving Delphi argumentation concerning promising technology generalizations. In this paragraph, I will suggest a classification of rational arguments in a technology foresight Delphi study.

#### 1. *Option suggesting arguments*

We already discussed the logical form of option suggesting arguments in the previous chapter. It is based on the idea, that an unrealized technology generalization belongs to the same similarity group than an already realized generalization:

- A generalization  $a_2$  which is not yet realized is promising based on the paradigm A because the generalization  $a_1$  is realized or
- A generalization is promising because it belongs to a promising similarity group of generalizations based on a technological paradigm A. The similarity group is promising because of the general evidence of theoretical considerations or because it includes realized generalizations.

An option suggesting argument opens the discussion concerning the validity of an option. The "starting validity" of an option suggesting argument is based on the technical validity (I and F) of the similar technology generalization and on the "epistemic power" of the similarity relation. If the similarity relationship is based on the rules of the paradigm and an actor accepts the paradigm, its starting validity for him is considerable. The person who suggests an option should also have some idea of the relevancy (R) of his suggestion. It is the starting point for further considerations about relevancy.

#### 2. *Arguments concerning genuine invariances*

Improvement of the validity of an option proposal concerning impacts on targets (I) and feasibility of the technique (F) is based on arguments concerning genuine invariances. They expose more or less validated invariances of the behavior of not-learning beings. We can e.g. exactly describe how DNA is multiplied in the polymerase chain reaction (PCR) and how the new technique can be used to find "DNA fingerprints". A genuine invariance always improves the validity of future argumentation. If the argument is not well validated we have to evaluate how re-

liable the source of the argument is. Another possibility that we try to find new evidence (for example make scientific experiments).

### 3. *Arguments concerning transient invariances*

Transient invariances tell about the stable elements of the behavior of actors or learning beings. The reliability is the often used measure of this stability. We may assume that actors will behave as they have behaved earlier or will change their behavior as they have changed it in the past (trends of behavior). We may assume that learning, at least on the aggregate or group level, does not significantly change behavior. Arguments concerning transient invariances have an impact, especially on the reliability of relevancy (R) evaluations. For example the next type of argument might improve the reliability of relevancy evaluation:

According to a statistically significant opinion measurement, x% of the sample of the Finnish women with children under 3 years of age considered that they do not need more information about possible hereditary diseases of their future babies.

Often arguments concerning transient invariances are based both on the behavior of actors or learning beings and on the implicit or explicit assumptions concerning the behavior of not-learning beings. We may e.g. have a "megatrend" which suggests that the use of the World Wide Web will increase by 30% annually. This trend is based on both the behavior of people and on the development of techniques used in the WWW.

### 4. *Arguments concerning reasons for relevancy evaluations*

It is important to realize that the reliability of a relevancy evaluation of some actors does not guarantee its validity. As we will see later, transient invariances might produce *predictive reasonability* (or validity) but not necessarily *option or commitment reasonability*. The arguments based on transient invariances assume that at least on the group or population level no learning happens. The purpose of arguments concerning the reasons of relevancy evaluations is just the opposite: their purpose is to produce epistemic reasonable learning. As I discussed in the first chapter, rational learning can be based on putting every aspect of the relevancy evaluation to the test of

- Serious refutable evidence
- Referentially relevant evidence
- Causally relevant evidence
- Causal independence
- Non-contradictory criteria of sameness of an actor.

### *5. Arguments concerning the capacity limits of relevant actors.*

Arguments concerning the capacity limits are important for the feasibility (F) of a technique: do the relevant actors have the resources needed to realize a technology generalization option? Arguments concerning capacities to produce alternative technological options are also important concerning the minimum level of the epistemic utility of realized technology generalizations (L). Relevant actors have only limited resources, which means that only a limited number of options can be realized.

## **3.7 Process Arguments and Expert Judgments as Proxy Evidence**

We have so far discussed five basic types of factual arguments: options suggesting, genuine-invariances-related, transient-invariances-related, relevancy-related and capacity-related arguments. We may also speak about two further basic types of arguments which I call proxy arguments: process arguments and arguments based on judgments of experts. The common feature of these two further types of arguments is that their connections with the epistemic utility of argumentation is indirect. Process arguments concern the feasible ways to produce arguments. Expert judgments are supposed to be based on tacit or hidden knowledge (factual arguments) of experts.

### *6. Process proxy arguments*

As I remarked above, the starting points of my epistemic utility model are very close to the "bounded rationality" concept of March and Simon (1958). It is possible to build further connections between concepts of March and Simon and my concepts. A rigidly used technology generalization can be seen as a special case of a "program" (March and Simon 1958,141):

... an environmental stimulus (e.g. some concrete targets, my addition) may evoke immediately from the organization a highly complex and organized set of responses (the use of a specified technique, my addition). Such a set of responses we call a performance program or simply a program... Situations in which a relatively simple stimulus sets off an elaborate program of activity without any apparent interval of search, problem solving, or choice are not rare.

The interpretation in my epistemic model is that the technology generalization connecting the concrete targets and the technique is without further considerations accepted by the organization  $k$  to be higher in value than  $L_k$  and realized. No argumentation process or search process - using the concepts of March and Simon - are started concerning e.g. validity or relevancy. No comparisons are made with other options which might have e.g. an impact on  $L_k$ .

A "routine realization of a technology generalization" or more simply routine use of a technique for some purpose can be seen as a special case of the "performance program" of March and Simon. An important feature of a routine realization is that the actor expects that it is not reasonable to produce new arguments for comparing the routine and other (possibly unidentified) options taking into account the cost of a search process. Using the concepts of my model, a further argumentation process is not expected to produce more enough epistemic utility.

Another way to approach both the routine use of a technique and the routine use of decision rules can be based on the concepts *ex ante* and *ex post* rationality (Eliasson 1996, 88). Eliasson considered that to be rational requires that one is consistent in one's decisions and selects the best *ex ante* option (optimization), given the available information. This can be prevented by two things:

- knowledge may be lacking,
- the decision situation may be too complex.

Both circumstances may make the *ex post* outcome differ from the *ex ante* evaluation. If an actor uses a technology generalization in a stable economic environment she can often rationally - based on the past experience - consider that *ex ante* and *ex post* rationality of a routine realization do not differ. In a continuously changing and complex economic environment, past experience cannot, however, guarantee the identity of *ex ante* and *ex post* rationality of a routine.

Can a decision in a complex environment be rational? Let us assume that a search process can produce only poorly validated future technology generalization options. Can the final judgments concerning the realization be rational in that situation? According to Eliasson (1997, 88) rationality requires in a complex situation that *ex post* error correction is part of the *ex ante* decision. The weight given to that error correction in the *ex ante* decision determines the decision maker's attitude to risks.

According to Eliasson, the argumentation in a complex decision making situation has two special features:

1. in the decision making, more complex information can be taken into account than can be presented or communicated (tacit knowledge),
2. when complexity becomes too large, simplification is resorted.

The simplification is needed for coordinated action. The choice of the decision-making model, which Eliasson considers to be an important decision, is connected with the fact that an organization cannot function properly without simpli-



fying rules which the members of the organization realize. This is the reason for the use of the concept "reasonability" instead of "rationality" above.

In complex decision making situations, *process arguments* concerning decision making rules can be decisive. Process arguments do not suggest the validity of a target-technique relationship or the relevancy of a technology generalization but they propose ways to evaluate it or to monitor it in the future. They may suggest how to evaluate the validity of produced factual arguments and when to start a search process of arguments concerning new options or routine technology generalizations. They may propose necessary conditions for starting a realization process of an option (e.g. a realization project in a firm) or sufficient conditions for stopping an innovation process. Eliansson (1996) stressed the importance of the early identification of business mistakes in a complex business environment. Efficient central capacity to identify lower level mistakes makes the organization less risk averse.

In a technology Delphi study process, arguments concerning the monitoring of new factual arguments relevant for discussed topics or issues are an important way to reduce the risk of accepting an option too early or too late<sup>2</sup>. In a situation where the validity of argumentation concerning a technology generalization is low, process arguments may radically reduce the risk of allocating resources to invalid options. If a process argument provides a good way to avoid the bad consequences of the choice of an invalid option, it has a similar role to an argument which improves the validity of argumentation. Hence it improves the epistemic utility of a technology generalization option.

Eliansson (1996, 90) heavily stresses the role of process arguments. The process arguments frame and edit an economic environment. According to Eliansson, an optimization can be performed in a framed and edited environment; the latter is a trivial task compared with the first choice process.

The framing and editing of an economic environment is based on traditions of organizations. The choice of the rules of an organization or its tradition is a path dependent learning process. As in the case of technological or scientific paradigms, it is practically impossible to anticipate the specific forms of traditions in an organization because the number of possible choices of rules is virtually unlimited.

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<sup>2</sup> Like Cuhls (1998, 62-80) I like to see topics in technology Delphi studies as continuously changing and developing options ("Ziele" in Cuhls' terminology) in the networks of other more general or more specific options. As Cuhls has remarked (p.66): "Die Zielbildung ist ein zeitverbrauchender Prozess, kein punktueller Akt".

Not all process arguments or traditions are, however, reasonable from the point of view of the epistemic utility. A tradition is not reasonable if it hinders the acceptance of validated arguments. A routine may e.g. systematically overlook some types of valid arguments because they do not belong to the “core competence area” of a firm.

### 7. *Expert judgments as arguments*

As Eliasson (1996) remarked, in complex decision making situations, more information can be taken into account than can be presented or communicated. The difficulty is that much of the relevant information is in the form of *tacit or hidden knowledge*.

Following the guidelines of Nonaka (1994), Annele Eerola (1996, 1993) has described the problem of the knowledge as follows:

... in most practical contexts knowledge that can be expressed in words and numbers only represents a small fragment of relevant knowledge: most people - among them highly educated experts - frequently experience the problem of knowing more than they are able to tell. In the context of technology studies we can, in fact, speak about two different types of knowledge: *explicit knowledge* on emerging technologies that is transmittable in formal, systematic language and *tacit knowledge* on factors affecting technological development that is hard to formalize and communicate, because it is deeply rooted in action, commitment and involvement in a specific context. In addition to the relatively concrete things, like contextual know-how, crafts and skills, even people's images of reality and visions of the future are involved in their tacit knowledge.

Collins (1994) has described the role of tacit knowledge in a technological innovation process. In the late 1960s, many laboratories throughout the world were attempting to increase the power output of gas lasers by increasing their operating pressure. Early in 1970, a Canadian research laboratory ("Origin") announced the "Transversely Excited Atmospheric Pressure CO<sub>2</sub> laser" (TEA-laser). In 1971, Collins studied seven British laboratories who had built or were building TEA lasers. Collins' main interest was to study the modes of transfer of real, usable knowledge among a set of scientists.

Most British scientists first heard that the laser had been successfully operated from a small "note" in the New Scientist. The first article in the formal journals appeared six months later in Applied Physics Letters. This article provided more detail, but, as events proved, insufficient to enable anyone to build a TEA laser.

Some respondents of Collins stated that the early articles were more misleading than helpful. A member of "Origin" commented:

What you publish in an article is always enough to show that you've done it, but never enough to enable anyone else to do it.

Skills were not transmitted through the medium of the written word. The laboratories studied actually learned to build working models of TEA lasers by contact with a source laboratory, either through personal visits and telephone calls or transfer of personnel.

In this special case, there was no open intent to hide the findings because "Origin" was a public laboratory. This "scientific openness" was, however, a half truth. Tactics for maintaining secrecy were less forthright. One tactic was to answer questions, but not actually volunteer information. As one informant put it: "let's say I've always told the truth, but not the whole truth". Nearly every laboratory expressed a preference for giving information only to those who had something to return. The importance of friendship relations explained in part the isolation of a Scottish laboratory from the other British laboratories.

According to Eerola (1996,193) we can see four different modes of knowledge conversion that are of interest when creating technology foresight: 1) explicit articulation of tacit knowledge ('externalization' in Nonaka's (1994) terms), 2) conversion of explicit knowledge to tacit knowledge ('internalization'), 3) conversion of existing tacit knowledge to new tacit knowledge (through 'socialization'), and 4) reorganization of existing explicit knowledge to new explicit knowledge ('combination').

When producing information on future technologies, the participants' ability and willingness to externalize their tacit knowledge can be a key factor in creating essentially new knowledge on important issues. According to Eerola, redundant information for concept development and successive rounds of dialogue in the atmosphere of mutual trust may be needed for this purpose. Creation of mutual trust can then be a challenging task, if it doesn't naturally grow from shared experiences. In this respect, the starting point of 'private studies' within individual companies can be better than in other types of technology studies.

As the case study of Collins (1994) also shows, it is reasonable to speak about "hidden knowledge" beside tacit knowledge. Hidden knowledge can be explicit or tacit. An argumentation process concerning a technology generalization, e.g. a Delphi study, is a process in which potential arguments or judgments are based on tacit, hidden or explicit public information. The nine basic possibilities are given below.

*The arguments after the argumentation process for  
an expert who did not know it before the process*

	Tacit	Hidden	Explicit
<i>An argument for an expert knowing it before an argumentation process</i>			
Tacit, does not like to hide	A	B	C
Likes to hide	D	E	F
Is ready and able to tell	G	H	I

*An expert judgment as an argument* or as a producer of epistemic utility can be based on the idea that the experts have some evidence which they cannot express though they are ready to express it (case A), do not like to express it (cases D and E) or forget to express it (cases G and H). Though panelists - using the concepts of Nonaka - might in some way "internalize" or "socialize" the factual arguments or hints given by other panelists, they often cannot explicate to non-experts what they have learned. Internalization of the messages of unclear arguments is evidently much easier for those repeatedly and interactively making use of similar tacit or hidden knowledge - e.g. for R&D experts or for professional planners - than for outsiders.

Though there are good reasons for the use of expert judgments based on tacit or hidden knowledge, there are, however, two difficult problems in judgments based on implicit arguments:

- 1) how to be sure that judgments are made by real experts having relevant tacit or hidden knowledge and
- 2) how to be sure that they do not hide their knowledge or use honestly their relevant tacit or hidden knowledge honestly in their judgments?

The technology foresight studies are much based on the idea of expert judgments as arguments. The praxis of many technology foresight Delphi studies has been the production of "proxy evidence" based on expert evaluations (or judgments) without factual arguments.

The production of proxy evidence has focused on "topics". A Japanese definition of "topic" was as follows ( IFTECH 1988,17):

Topic refers to technological breakthroughs, events, or changes, each expected in the future of Japan, some of which may already have taken place outside of Japan. In the latter cases, this refers to domestic realization through the introduction of technology from abroad or international joint development.

In the six national technology foresight studies made in Japan 1971-1997, the number of topics has increased from 644 to 1072 (NISTEP 1997)<sup>3</sup>. According to Kerstin Cuhls (1998), the topics in the Japanese Delphi studies are used more as options<sup>4</sup> than as events. In fact, Cuhls, who has made comparisons with Japanese and German national technology Delphi studies, has interpreted topics ("Thesen" in German) as targets or sub-targets ("Ziele"), but she clearly speaks about a combination of targets and means<sup>5</sup>. According to Cuhls (1998,70):

Because few governmental target documents for research and development or for the economic development are published (in Japan), a Delphi study as an overview of future developments is welcome. The topics represent a cluster of long range, medium range and short range targets ("Ziele")<sup>6</sup>. "The STA Delphi study is sometimes the only TF (technology foresight) result available to most firms. Therefore many firms are forced to rely on its result. More specifically, many firms choose one or two particular approach(es) among several alternatives according to the result of the Delphi study. Similarly many firms set target dates of their projects according to it. In this way the STA Delphi study tends to unify the approaches of different firms and to synchronize the target dates of the technologically related projects under the independent management" (Eto 1984)

Another interpretation which is near to the idea of Cuhls is that topics are "mini-scenarios" or visions believed or not believed by experts. This idea is very clear in the report of the last German national Delphi study, (Cuhls et al. 1998b, 9): "For these topic fields, altogether 1070 future visions were raised. In the topic

<sup>3</sup> The number of topics was higher in the 5th study: 1149.

<sup>4</sup> In the framework of the GTC topics function very much as interests or as subinterests.

<sup>5</sup> Cuhls (1998,71): "Aber auch hier werden Ziele ("... Technik A kann für X eingesetzt werden") aufgestellt". The same idea is also very clear in the figure 25-5 on the page 78.

<sup>6</sup> Cuhls (1998, 69) describes the role of targets on different levels in Japan as follows: "the great targets are not ... very concrete. They become concrete only with the time. The subtargets (or subsubtargets) are still flexible, but already very specified. They are divided in special operational projects with exact plans. The plans are proved in these special projects..." And later (p.74): Die Teilziele, die es in der Forschung und Entwicklung zu erreichen gilt, werden allerdings sehr konkret vorgegeben (zeitlich, Kosten usw.) geplant und die Einhaltung strengstens überprüft. Wenn jedoch ein Teilziel nicht in der Zeit eingehalten wird, kann und wird der Gesamtplan angepasst - und nicht wie in Deutschland often üblich - verworfen.

areas (Themenfeldern) have been made 1070 visions of the future in the form of topics (Thesis)..."

If we accept the idea that topics should be continuously developing options or mini-scenarios for the developing work we are very near the idea that topics should be promising technology generalization proposals. This interpretation is consistent with the following parameters set by the technology forecast committee for the last national Japanese study (NISTEP 1997, 2):

- In principle, topics that have no technological elements and are connected only to socioeconomic conditions should not be included in the survey.
- Topics should include specific objective values and champion data wherever possible, and should present an image of specific use and application.

Many topics of Japanese (and German) national Delphi studies have actually had the form of a technology generalization. A clear example is e. g. the following topic (IFTECH 1988, 92):

Widespread use of ultrasonic, underwater holographic technology capable of application for probing underwater objects.

Often however either only a promising target or only a promising generic technology have been mentioned in the definition text of a topic (IFTECH 1988, 84, 44 ):

Landing and return of manned spacecraft from Mars.

Practical use of semiconductor lasers emitting blue light.

Though many topics do not include explicit suggestions concerning target (or impact) - technique relationships, it is very reasonable to assume that "proxy arguments" of national technology Delphi studies actually concern explicitly or implicitly defined technology generalizations. It is possible to evaluate the "proxy evidence" from the point of view of the model of the epistemic utility, though all topics surely do not meet the requirements of "reasonable technology generalization proposals from the epistemic point of view" defined above. I consider, that a topic in a national technology Delphi study has been something between an "issue"<sup>7</sup> and a reasonable technology generalization proposal with specific technique(s), specific impacts and an implicit validation method.

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<sup>7</sup> I will discuss the role of issues in technology Delphi studies in the connection of my Argument Delphi in the paragraph 3.10.

The fifth Japanese fifth national technology foresight Delphi study and the Delphi I of Germany, contain evident "proxy" measures of the variables of the epistemic utility model (Cuhls and Kuwahara 1994). The degree of the importance of each topic was measured with evaluations of Delphi panellists on a scale of high-medium-low-unnecessary. This evaluation refers both to the impacts of the technology (I) and the relevancy (R). From the scale, it follows that there cannot be a topic which is evaluated to be undesirable and feasible, only unnecessary and feasible. This implies a questionable assumption that the realization of the topics is always a positive happening, though more or less important.

In the Japanese- German study experts evaluated the realization of a topic based on the following constraints. They were asked to choose a maximum of two from among eight choices (Cuhls and Kuwahara 1994, 40-41):

- a) "Technical constraints": Various technological factors which are difficult to resolve.
- b) "Institutional constraints": The restrictions placed by law and regulations or unimproved standards or requirements.
- c) "Cultural constraints": The sense of values of society, cultural and climatic factors or other similar factors.
- d) "Constraints in costs": The difficulty of reducing costs for reinforcing market competitiveness or for opening up markets.
- e) "Constraints in funding": Insufficient funding.
- f) "Constraints in fostering or securing human resources": Inadequate fostering or securing of human resources.

Anticipated cost constraints can be seen as a proxy measure of the feasibility (F). Proxy measures of feasibility were also perceived as technical, funding, human resources and R&D system constraints on topics.

Two proxy measures of the validity (V) of an evaluation were used. The first was the degree of certainty of an expert concerning the realization time of a topic. It was measured with the high-medium-low scale. Another measure of the validity was the self-evaluation of the expertise, which was also measured with the high-medium-low scale.

The subjective evaluation of importance was also a proxy of expert evaluation of the relevancy. Other proxies of the relevancy were institutional and cultural constraints. Actually, the evaluation of relevancy was not clearly distinguished from the evaluations of impacts and feasibility.

Both German and Japan have made new technology Delphi studies after their common study (Cuhls et al. 1998, NISTEP 1997). Though some changes have happened in the proxy indicators, e.g. the relevancy aspect is more clearly distinguished in the last German study, the basic logic has not changed. Beside Japan

and Germany e.g. France, the United Kingdom, Korea and Austria have made technology foresight Delphi studies based on proxy arguments of experts (Heraud et al. 1999, Loveridge et al. 1995, Shin et al. 1999, Delphi Report Austria 1, 1998). In these technology Delphi studies the proxy measures have in general been rather similar to those used in the common Japanese and German study. The different targets of the studies have, however, had impacts on the proxy indicators used. I will discuss the UK study (Loveridge et al. 1995) in more detail in paragraph 3.13.

I interpret the basic logic of the common Japanese - German national Delphi study as follows. If some panellist considers that the product (the impacts  $\times$  the feasibility  $\times$  the validity  $\times$  the relevancy) of a topic is high enough in some future year, he or she makes a judgment that the topic will be realized in that year. This means that the epistemic utility of the topic has to be for some actor(s)  $k$ , who can realize it, greater than the epistemic utilities of alternative choices (the epistemic utility of the topic is greater than the minimum value  $L_k$ )<sup>8</sup>.

I think that the above interpretation is in accordance with the interpretation of e.g. Cuhls (1998) that topics represent reasonable targets. Another possible interpretation is that Delphi panellists try to make true predictions concerning the realization times of topics. The predictions of future events could be based on the following logic. The realization time of a topic depends on the importance of the topic and the constraints on realization of the topic. The insecurity of the exact time of realization is measured by the certainty expressed concerning it and by the self-evaluated expertise.

A hint that the focus in the technology Delphi studies has moved from the prediction towards reasonable choices is that the insecurity measure of the exact time of realization was removed from the later German and Japanese Delphi studies (Cuhls et al. 1995, NISTEP 1997, Cuhls et al. 1998).

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<sup>8</sup> Let us assume that the discussed topic is a possible technology generalization  $g$ . The minimum requirement for the realization of  $g$  is that the total value of  $I_g \cdot F_g \cdot V_g \cdot R_{gk} - L_k$  has to be higher than zero for some relevant actor  $k$ , who can realize  $g$ . In that case, the realization of  $g$  belongs to the perceived capability limits of  $k$ . An interpretation of the logic of the national Delphi studies mentioned is that  $g$  is supposed to be a real innovation. This means that a Delphi panellist considers that  $g$  belongs to real capability limits of actor  $k$ , which means that  $k$  will not regret the realization.



### 3.8 Predictive, Option and Commitment Reasonability

#### 3.8.1 A basic epistemic problem in technology foresight based on expert judgments

What is the epistemic value of the "proxy" arguments based on expert evaluations or processual arguments discussed in the paragraph 3.7 in comparison with factual arguments discussed in the paragraph 3.6? I will discuss this question with a comparison of the epistemic values of a factual argument (A) given in my study (Kuusi 1991) and a "proxy" argument (B). They both motivate the same topic or technology generalization proposal b:

The specifically Finnish hereditary diseases will be extensively diagnosed using methods of genetic engineering in Finland in 2005

Let us first look at the factual argument:

(A) The problem of hereditary diseases is more difficult in Finland than in many other countries. Besides the internationally important hereditary diseases, the Finnish population has many fatal or disabling hereditary diseases which other nations do not have. New methods like the polymerase chain reaction (PCR) provide new opportunities for diagnoses.

Let us suppose that the argument is new for the decision-maker  $k$  who makes a realization decision concerning  $b$  based on its epistemic utility. Because the argument is valid, it in any case has a positive net impact on the epistemic utility of  $b$ . In addition to a positive validity effect the argument increases the value of impacts of  $b$  (= the finding of the hereditary diseases of fetuses) or  $I_b$ , if  $I_b$  is e.g. measured by the avoided costs of babies with hereditary diseases. The argument mentions also a new efficient technique PCR resulting in a higher value of  $F_b$ .

In this specific case the role of  $R_{bk}$  is, however, probably most important to the total value of the argumentation concerning generalization  $b$ . If the decision-maker  $k$  gives - for ethical reasons not taken into account in the value of  $I_b$  - assign only a little value to the produced impacts, he or she shows it through a low value of  $R_{bk}$ . The result is perhaps that the total value of  $I_b F_b V_b R_{bk}$  is below  $L_k$ . So the "realization value" of generalization  $b$  is 0 for  $k$ .

What is the value of  $R_{bk}$ , if instead of the above well-validated factual argument we have the following similar argument, which could be the form it might take in a technology Delphi study:

(B) 60% of the experts, evaluating themselves high in expertise on the topic, considered that it will be true.

Let us suppose that the implicit or tacit factual motivation of the argument (B) is just the same as in argument (A). If judge  $k$  believes in the real expertise of the experts used the value of argument (B) can, however, be higher than the value of argument (A). If  $k$  firmly trusts on the experts she may even forget her ethical considerations and give a high value of  $R_{bk}$ . The total value of  $I_b \times F_b \times V_b \times R_{bk}$  is now over  $L_k$ . Hence we see from the formula that the "realization value" of generalization  $b$  is above 0, which means that  $k$  believes in the realization of generalization  $b$ .

The point in the above comparison is that the conclusion based on the first argument is reasonable but the conclusion in the second case is not. The proxy arguments describe wrongly the tacit knowledge or factual arguments behind the proxy arguments based on the fallacy called "argumentum ad hominem" ( Woods and Walton 1982).

### 3.8.2 Three types of reasonability of argumentation

A realized technology generalization is often based on wrong premises. *The main target of technology foresight studies is not to anticipate wrong decisions but to avoid them.* What does this mean concerning the topic:

In 1999, the fetuses of all pregnant women in Finland who give their consent will be examined for at least three hereditary diseases with new methods, either for a small remuneration or no remuneration at all.

My expert panel made a judgment concerning it; 75% rejected it. As I already mentioned, a statistically significant opinion measurement of Finnish women with children under 3-year of age would have produced a more predictive valid result. But what about the reasonability of the judgment?

I make a distinction between three types of the reasonability of a judgment: predictive reasonability, the reasonability of options and commitment reasonability.

In *predictive reasonability* the focus of both arguments and judgments is in the anticipation of the - reasonable or not reasonable - actions of relevant actors, without trying to make an impact with arguments on the behavior of those actors. With the *option reasonability*, I refer to an argumentation process where every actor or every panelist in a Delphi study produces epistemic rational arguments or

compares different future options from his or her personal point of view or from the point of view of his or her organization. The arguments produced are evaluated on the basis of the personal values of relevance or R and personal values of newness or N. If the focus of a Delphi study is the reasonability of options, we obtain arguments and judgments which are important and valid at least for some actors represented on the panel.

The idea in *commitment reasonability* is to build reasonable coalitions of actors for realizing future options. The arguments produced in an option reasonable argumentation process are evaluated from the viewpoints of different actors. It is realized that the evaluations of relevant actors are more important than the evaluations of actors for which a future generalization of a technology is less important or which does not have relevant resources realizing the generalization.

Let us assume that the Finnish government is so worried about the use of gene technology in the diagnosis of hereditary diseases that it appoints an expert committee. From the mandate of the committee, we may infer which type of reasonability the government expects from the experts. If the mandate is to evaluate how some other countries will diagnose fetuses in 2010, predictive reasonability is supposed. If the mandate is to make an extensive survey of the possibilities for diagnosis of fetuses in Finland in 2010, the focus is on option reasonability. If the mandate is to make a plan for 2010 concerning future use of the diagnosis of hereditary diseases including the roles of different organizations, the focus is on commitment reasonability.

An important point is that the epistemic value of an argumentation process (or a Delphi study) depends on the type of reasonability expected. I will illustrate this by comparing the argumentation of the author's Delphi study with the hypothetical opinion research from the perspectives of different types of reasonability. Let us suppose that all arguments are equal in newness, which means that this dimension is not relevant to the comparison. Let us use a simple quantification where the impacts of the technology generalization (I), the feasibility value of the techniques (F), the validity value of argumentation connecting impacts and techniques (V) and the relevance of argumentation (R) are all measured all on a scale of 0-5. The assumed values in the following discussion are of course only for illustration.

We may assume that the predictive reasonability value of an argument depends on the ability of the argument to describe the average attitude of Finnish people concerning the topic in 1999.

What is the contribution of the Delphi study to the predictive reasonability? We may assume that in 1999 an average of 50% of the Finnish people will know the arguments 1,3, 5 presented in the paragraph 3.3. If knowing people give on aver-

age 2 points higher I-value to the topic than not-knowing, the total effect on the I-value is 1. We may also assume that 50% of people will know the arguments 2 and 4 and if on average the F value of knowing people is also 2 points higher than of those not knowing, the total effect of arguments on F-value of the topic is 1. Let us suppose for simplicity that arguments have no effect on the average level of the validity of argumentation V. Because of ethical considerations and because they are suspicious about the ethics of the experts, their average relevancy value may be rather low, let us say 2.

Let us suppose that the final decision of the realization of the topic in 1999 is based on a comparison of the epistemic value  $IxFxVxR$  with the minimal feasible realization value L. Let us suppose that this minimal value is 25.

We may assume that the result of the hypothetical opinion research represents the present 1999 value of Finnish people of  $IxFxVxR$ . Let us suppose that it is  $2 \times 1 \times 3 \times 2 = 12$ , which is clearly lower than 25. The value on which the realized "no" decision in 1999 is better informed. It is  $3 \times 2 \times 3 \times 2 = 24$  which is still lower than 25. Therefore, the predictive reasonability of argumentation based on the present opinions is so high.

It is important, however, that the epistemic utility value related to the predictive reasonability is always below the level of epistemic utility which can be produced by further option rational or commitment rational argumentation. In the above example, we might suppose that 75% of the citizens instead of 50% could know the arguments 1-5 as a result of further argumentation. In that situation they would have made a more reasonable judgment concerning the discussed technology generalization:  $3,5 \times 2,5 \times 3 \times 2 = 28,5$ . This is higher than 25 and it makes the predictive reasonability of argumentation based on the present opinions invalid.

Though every future topic can be viewed from the perspectives of predictive reasonability, option reasonability and commitment reasonability, different types of reasonability are relevant in different situations. The future topics can be divided into three types based on the motives of the anticipation:

- 1) A topic is asked, which cannot be affected by the action of the panellists or the customers of the study. In this situation, predictive reasonability dominates. Panellists have to look at the future topic as outsiders.
- 2) Panellists or their customers may have an impact on the anticipated future, but they are especially in lack of relevant decision alternatives or relevant future options. In this situation, the option reasonability dominates in the argumentation and in the making of judgments.
- 3) Panellists or customers have an impact on the anticipated future and they know relevant future options well enough, but realization of the options depends on the

coordinated action of many decision makers. In this situation the commitment reasonability dominates in the argumentation.

If the prediction reasonability is the main focus of a study, the *accuracy of predictions* can be seen as the main criterion of success. If the customers of the study have defined specific topics of prediction (will some specified events happen or will they not), the accuracy can even be seen as the sole success criterion. If the topics are, however, vaguely defined, the relevance of predictions is another main criterion beside accuracy. The predicted topic has to be important to the customers. In that case, there are two necessary conditions for the prediction reasonable epistemic value of a generalization b:

- (1)  $I_b F_b V_b \times R_b A$  is over  $L_A$ , where A is a group of actors whose actions are sufficient for the realization of b. A has to be committed to realize b.
- (2) b is rationally relevant for the group of customers of a prediction study

In order to predict the realization of b, arguments concerning the real capacity limits and perceived capability limits of A are crucial while arguments concerning the perceived capacity limits and real capability limits of A are not so important. It is namely reasonable to assume that realized actions are based on perceived interests (perceived capability limits) and on real resources. The discrepancy between perceived and real capacity or capability limits may, however, also anticipate the possible impacts of learning on the behavior of actors.

If the option reasonability is the main focus of a study, the main success criterion is *the total epistemic value of the exposed new rational options (and arguments) to the relevant actors*. Behind relevant options are often different ideas, paradigms or, using the concepts of the GTC, different systems of criteria of sameness. Already de Jouvenel (1967, 251- 259) stressed the role of finding relevant ideas by conducting foresight:

Our different angles of vision bring out different facts. Our value-judgment is not so much subsequent to our reading of the fact, as it is immanent in the ideas we use in reading the facts... Whatever external use a science is put to, its inner life is characterized by the progress of ideas... On the assumption that changes in society are the result of changes in ideas, we cannot forecast the former without forecasting the latter... What I mean by the forecasting of ideas is forecasting their diffusion, deformations, and applications.

If the option reasonability is the main focus of a study, there is one necessary condition for the epistemic value of arguments concerning a generalization b:

(3)  $I_b F_b V_b \times R_{bk}$  is over  $L_k$ , where  $k$  is any reasonable actor, who is reasonably relevant for the realization of  $b$  from the point of view of the group of customers of the options seeking study.

The final epistemic value of the argumentation depends on both its relevancy and on its newness. The concept "rational" includes the idea that different types of arguments are relevant for predictive reasonability and for option reasonability. For predictive reasonability irrational arguments also are relevant if they have an impact on the future generalization  $b$ . Reasonability is required only in the relevancy evaluations of the study customers (the condition (2)). In an option reasonable argumentation the focus is, using the concepts of GTC, on capability limits after the rational arguments (or a learning process) instead of perceived capability limits before the argumentation. If a technology generalization is within real capability limits of an actor, it is also within her real capacity limits.

A problem in the option reasonability is the scope of the argumentation. An option reasonable argumentation or communication process can produce rational arguments but they may be biased to the interests of some actors. A result of the biases may be a discrepancy between the prediction reasonability and the option reasonability. The right predictions require the anticipation of the behavior of relevant actors. If the relevant options of key actors are not discussed, the option reasonable argumentation does not anticipate the future developments. That type of argumentation cannot even improve the reasonability of decision making of the customers of the study. Hence according to the condition (3) every argument is valuable which has epistemic value to an actor who is rationally relevant for the realization of  $b$  from the point of view of the group of customers of an options-seeking study.

Because every generalization of a technology is a leap into unknown - as was discussed in the previous chapter - an actor actually perceives a distribution of possible outcomes of a technology generalization enterprise. For different outcomes different arguments are relevant. It is often useful to divide options seeking studies in "minmax" -studies or "providing for bad alternatives (dystopies)" - studies and "maxmax"-studies or "opportunities seeking"-studies using concepts from game theory (Luce et al.1957). The idea in a minmax-study or a risk-averting-study is to find relevant options for a strategy which maximises the benefits in the worst futures. The idea in a maxmax-study is to find relevant options for a strategy which can produce - even with a risk of losses - maximal benefits.

The main success criterion in a technology foresight study focused on commitment reasonability is *the total epistemic value of the relevant rational decision options to which relevant decision makers are ready to commit themselves*. It is possible to give two necessary conditions for this type of epistemic value:

(4)  $I_b F_b V_b R_b A$  is reasonably over  $L_A$ , where A is the group of actors whose actions are decisive for the realization of b.

(5)  $I_b F_b V_b R_b B$  is reasonably over  $L_B$ , where B is the group of customers of the commitment producing study.

Like in the option reasonability, the final epistemic value of the argumentation depends on both its relevancy and on its newness. The fourth necessary condition is identical with the first necessary condition of prediction reasonability, except the form includes the word "reasonably". Like in the option rational argumentation, the focus is on capability limits after the argumentation (or a learning process) instead of perceived (e.g. irrational) capability limits before the argumentation. The fifth condition says that the decision options concerning technology generalizations have to be reasonable for realization for the group of customers of the commitment-producing study.

In practice, there is another way to define commitment reasonability. It is often so that the interests of the customers of the study concerning the generalizations differ from the interests of the actors whose actions are decisive for the realization of generalizations. Let us suppose that we have a generalization suggestion which is reasonable from the point of view of the customers of the study but not from the point of view of some decisive actors. In this situation from the point of view of the special interests of the customers, it is reasonable at least in the short run that decisive actors do not behave rationally. Instead of (4) we get another condition (4'):

(4')  $I_b F_b V_b R_b A$  is not necessarily reasonably higher than  $L_A$ , where A is a group of actors whose actions are decisive for the realization of b. The group of customers of the study B is, however, able to inform (or to manipulate) A so that A perceives  $I_b F_b V_b R_b A$  to be higher than  $L_A$ .

In this case of *customer oriented commitment reasonability* or *weak commitment reasonability*, the focus is on the manipulation of A. B can use the knowledge concerning the perceived capability and capacity limits of A as well as the knowledge concerning the real capability and capacity limits of A for manipulation of the actions of A. Using this knowledge and manipulating the learning processes of A, the customers B can make A to commit themselves to actions which result in the realization of b. The weak commitment reasonability means that though b is reasonable based on the epistemic utility from the point of view of B, it might not be reasonable from the point of view of A.

### 3.8.3 A classification of reasonable generic technologies

I have above discussed the reasonability of single technology generalizations. The prospects of a generic technology or of a technological paradigm can be described by its reasonable generalizations. Reasonable generalizations define all reasonable impacts or targets and all reasonable techniques of a generic technology. Any positive target or impact of a technology generalization includes also caused negative side-effects or impacts.

All realized targets and techniques are predictive reasonable simply because they are realized. All of them are, however, not necessarily option or commitment reasonable. One can often expect that realized generalizations which are neither option nor commitment reasonable will in the future disappear. The realization of a generalization might, however, make it reasonable because of sunk investments. Technological paradigms are bundles of reasonable generalizations and not bundles of separate targets/impacts or techniques. A rough classification of technological paradigms or generic technologies can be based on all realized and promising targets or techniques.

We might characterize realized achievements of technological paradigms with the following types:

- A. One or a few realized targets with one or a few realized techniques.
- B. One or a few realized targets with many realized techniques.
- C. Many realized targets with one or a few realized techniques.
- D. Many realized targets with many realized techniques.

Based on promising techniques and targets the analogous classification is as follows:

- A'. One or a few promising targets with one or a few promising techniques.
- B'. One or a few promising targets with many promising techniques.
- C'. Many promising targets with one or a few promising techniques.
- D'. Many promising targets with many promising techniques.

Some generic technologies mentioned by Grupp (1993b) can illustrate how the above types A -D can be used in the classification of generic technologies based on their recent applications and future opportunities.

Fullerenes (or buckminsterfullerenes) are a good example of the case A. There are still only a few techniques to produce fullerenes and only few targets for their use. There are, however many possibilities to generalize the applications and techniques to handle these tiny carbon "footballs". It is very difficult to evaluate the future type of this generic technology. Will it be B',C' or D'?



*Buckyballs that everybody wants to use and nobody knows what to do with*

The title is from a review article in *The Economist* (August 23rd 1997). These molecules shaped like footballs (each one a near-spherical framework of 60 carbon atoms arranged in pentagons and hexagons). They are so neat that they have long seemed destined for great things - as building blocks for strong, lightweight structures, perhaps, or as molecular cages. These options can, perhaps, be realized with some new technique used to make fullerene polymers (e.g. Hirsch 1993). Perhaps fullerene polymers will open the way to fullerene superconductors (Travis 1993).

There is a fundamental technical problem or opportunity in the use of nice buckyballs. They are so stable that enchaining them into chemical reactions is exceptionally difficult. This property may be both a problem and an advantage. Laura Dugan, Tom Lin and their colleagues reported in 1997 their success in using buckyballs to protect nerve cells from damage caused by molecular attackers known as free radicals. These molecules are so reactive that they can destroy a wide range of important biochemicals. On meeting a buckyball, a free radical grabs at the bounty of electrons smeared across the bucky's surface, but cannot break it. The radical stays stuck to it like a leech. It is reasonable to assume that the technique-target connection realized by Dugan et al. is possible to generalize to many further uses.

The recombinant DNA technology is a key generic technology of the new biotechnology or cell-biotechnology as Grupp (1993b, 118) calls it. This technology is an example of the case B and it is reasonable to suppose that the type will not change in the future (B'). The main target of this technology will probably always be the same: the transfer of effective genetic material from one organism to another.

The technology of Polymerase Chain Reaction (PCR) or DNA multiplication is now a clear example of C. The same technique can be used for many purposes. It is an interesting question whether there will be many techniques for multiplying DNA in the future. Is the future type of PCR D'?

Digital technology is nowadays a good example of D. The number of different techniques and targets based on the idea "information sampling" of the digital technology is enormous. There is little sense to believe that this type of technology will change (D').

At the end of eighties Arthur D. Little developed a method for strategic technology management (Irvine and Martin 1989, 94-95). A phase in his technology strategy building process was the looking after promising technologies for the strategy builder. Little classified technologies into four categories according to their potential impact on competitiveness:

- a) *Base technologies* (essential for a given product or process but widespread and easily accessed)
- b) *Key technologies* (which provide a commercial advantage through product or process differentiation and through improved economics)
- c) *Pacing technologies* (not yet widely applied but having the potential to alter the basis of competition in the sector and therefore of high research priority)
- d) *Emerging technologies* (often still at a basic stage and with uncertain prospects, but with the promise of developing into pacing, and, perhaps subsequently, into key technologies).

What are the connections between Little's classification and my classification? It is reasonable to suppose that a technology which has the characterization BB', CC' or DD' for the actor and for its competitors is typically a base technology. If the economic profitability of present or possible future generalizations is higher for the strategy building enterprise than for competing firms, the generic technology is a candidate for a key technology. If global characterizations of technologies are e.g. AB', AC', AD', BD' or CD', but there are few or no applications of these technologies in the use of the strategy builder or its competitors we may call them pacing technologies. A technology in the global phase A with uncertain promises of important generalizations is a typical emerging technology.

### 3.9 Delphi Variants Focused on Option Reasonability

In this and the next paragraphs, I will evaluate the success criteria used and the results of some technology Delphi variants from the point of view of different types of reasonability. Two general conclusions can be drawn from the analysis below. Firstly, much confusion has resulted from the fact that different requirements of different types of reasonability have not been realized. Secondly, few technology foresight Delphi studies have been made that actually focused on only one type of reasonability. All successful technology foresight Delphi studies have to some extent taken into account most of the success factors summarized by Cuhls (1998,19-20) Cuhls' twelve success factors refer to all three types of reasonability:

- 1) to open new possibilities or options, which makes possible the priority setting and the evaluation of the results of the options and the possibilities of their realization;

- 2) to realize the impacts of the present technology policy;
- 3) to get early warnings;
- 4) to realize new needs and new technical possibilities;
- 5) to evaluate the consistency of a specified policy;
- 6) to give frameworks for planning and to have an impact on strategic planning;
- 7) to launch new ideas;
- 8) to restart interrupted developments to take up older ideas
- 9) to focus selectively on economic, technological, social, ecological aspects and to make observations and to do further research on these aspects;
- 10) to define the desirable and undesirable futures and the identification of inevitable events and action needed related to those events;
- 11) to make action proposals for the realization of desirable futures;
- 12) to stimulate continuous discussion processes about the future.

The success factors 2 and 3 are most closely connected with the prediction reasonability; 1, 4, 7, 9 and 12 with the option reasonability; and 1, 5, 6, 8 and 11 with the commitment reasonability.

In this paragraph, I will discuss the Delphi variants which are focused mostly on option reasonability. It is most reasonable to start from these variants because some level of option reasonability can be seen as a necessary condition for other types of reasonability. In other words: *it is impossible to produce other types of reasonability in a technology foresight (Delphi) study without an implicit or explicit option-reasonable stage.*

The Policy Delphi can be seen as the "mother" of many Delphi variants used especially for achievement of option reasonability (e.g. Turoff 1975). The idea of the Policy Delphi was introduced in 1969 for the first time and reported on in 1970 (Turoff 1975, 84). Instead of the consensus, it sought to generate the strongest possible opposing views on the potential resolutions of a major policy issue. Turoff introduced the Policy Delphi, because a policy issue is one, for which there are no experts, only informed advocates and referees. An expert may contribute a quantifiable or analytical estimation of some effect resulting from a particular resolution of a policy issue, but it is unlikely that a clear-cut (to all concerned) resolution of a policy issue will result from such an analysis.

Experts cannot do more than supply a factual basis for advocacy of policy issues. They must compete with the advocates of concerned interest groups within society or an organization concerned with the issue. In practice, their role is often not only to give neutral factual arguments concerning the planning issue. Experts represent the interests of their interest groups.

The clear focus of the Policy Delphi is option reasonability. Policy Delphi is for the analysis of policy issues and not a mechanism for making final judgments such as predictions or commitment-reasonable policy recommendations. Its target is to persuade an informed group to present all possible options and supporting or rejecting evidence for them. It deals largely with statements, arguments, comments and discussion.

Turoff (1975, 87) suggested that a Policy Delphi differs from a traditional Delphi in being able to serve any one or any combination of the following objectives:

- To ensure that all possible options are on the table for consideration
- To estimate the impact and consequences of any particular option
- To examine and estimate the acceptability of any particular option

The communication process of a Policy Delphi proposed by Turoff (1975) has six phases:

1) Formulation of the issues. What is the issue that really should be under consideration?

The initial design must ensure that all the "obvious" questions and sub-issues have been included and that the respondent is being asked to supply the more subtle aspects of the problem. With proper knowledge of the subject material, the design team can stimulate consideration of otherwise neglected issues by interjecting comments for consideration by the group.

2) Exposing options. Given the issue, what are the policy options available? There is a risk of swaying the respondent group towards one particular resolution of an issue. The special experts can sometimes be even less innovative than other experts because they are so inclined to ongoing development processes (Schrum 1985).

3) Determining initial positions on the issues? Which are the ones everyone already agrees upon and which are the unimportant ones to be discarded? Which are the ones exhibiting disagreement among the respondents?

Turoff stressed the importance of inducing discussion. In the evaluation scales proposed by him there are no neutral answers (a 'No Judgment' answer, however, is always allowed for any question). The lack of a neutral point promotes a debate. One will usually find a significant number of items which are rated desirable and unfeasible or undesirable and feasible. The discussion among the respondents about these items may lead to the generation of new options.

4) Exploring and obtaining the reasons for disagreements. What underlying assumptions, views or facts are being used by the individuals to support their respective positions?

5) Evaluating the underlying reasons. How does the group view the separate arguments used to defend various positions and how do they compare to one another on a relative basis?

6) Reevaluating the options. Reevaluation is based upon the views of the underlying "evidence" and the assessment of its relevance to each position taken.

Turoff (1975, 88) considered that in principle the above process would require five rounds in a paper-and-pencil Delphi procedure. He considered that in practice, it has been possible to restrict the number of rounds to three by utilizing the following procedures:

- The monitor team devotes a considerable amount of time to carefully preformulating the obvious issues.
- Sending the list with an initial range of options but allowing for the respondents to add to the lists.
- Asking for positions on an item and underlying assumptions in the further rounds.

Passig (1998) has presented a summary of the later Delphi variants with features similar to Policy Delphi. Decision Delphi adds new features to Policy Delphi. It does not deal with experts nor with lobbyist or advocates but with actual decision-makers. The panellists are recruited with regard to their actual position in the decision-making hierarchy (Ranch, 1979). In this procedure, anonymity is not fully implemented. The panelists' names are known from the beginning, but the responses are not identified with any one participant (quasi-anonymity). Another procedure based on quasi-anonymity is OSCAR (On-Site Conferencing and Researching) (Harkins et al. 1983). OSCAR, like many other similar methods, provides the opportunity to conduct multiple information gathering rounds in face-to-face settings such as workshops, while maintaining quasi-anonymity.

The Qualitative Controlled Feedback (QCF) (Press 1983) can also be seen as a variant of the Policy Delphi as well as the Imen-Delphi exercise ("the ability to emerge is in me") (Passig 1998). The Imen-Delphi is according to Passig a procedure for eliciting and refining non-expert group opinions about their future. Firstly, a panel concerned with a common future issue is collected. The procedure is based on the personal and group evaluations of the prepared summaries of previous forecasts and studies concerning the possible futures of the panelists. The procedure does not aim to predict events, but to generate an agreement for the purpose of developing a framework to realize the preferable and redefined

mission derived from it (Passig 1998, 319). Hence, the procedure is explicitly not-focused on prediction reasonability. Beside option reasonability, the Imen-Delphi is also focused on commitment reasonability.

### 3.10 Argument Delphi

I will present in this paragraph the main features of a Delphi variant which can be seen as a variant of the Policy Delphi. Because it is focused on the production of relevant (factual) arguments, I call it the Argument Delphi (AD). The basic features of the AD described below can be found from the Delphi studies in Kuusi (1991) and Kuusi (1994).

In the Argument Delphi, the panellists are informed about the names of the other participants but the responses are given anonymously as in the Decision Delphi. The main purpose is to make the panellists to argue seriously as in the Qualitative Controlled Feedback procedure. Only Delphi managers have direct contacts with the panellists in the first round interviews, unlike in the OSCAR process. Like in the Imen -Delphi, prediction reasonability has only a limited role in the study. My applications of the Argument Delphi have mostly focused on option reasonability. As I will discuss more closely at the end of this paragraph, in my last study (Kuusi 1994) I gave an opportunity to panelists to select the type of reasonability on which they based their arguments concerning any specific issue.

The Argument Delphi is based on a four level classification of statements. First we have *topics*. They are typically statements (e.g. future events) which experts evaluate. Topics have been typically evaluated in a very simple way: panelists have decided whether they approve or disapprove a topic. Topics are classified in *issues* including many topics. The topics of an issue are at least in part mutually exclusive. Issues are classified in *issue areas*. The idea of an issue area is that typically the same panellists are special experts (e.g. based on work experience) in an issue area.

The role of issues, including mutually exclusive topic statements, is to promote efficient argumentation processes. Van Emereen et al. (1996,280-288) have presented a model for critical discussion aimed at resolving a difference of opinion. It is an ideal model, specifying the various stages in the resolution process. It has four stages:

- 1) In the *confrontation stage* (or in the framework of the Argument Delphi in the choice of issues and topics) a difference of opinion presents itself through the opposition between a standpoint and nonacceptance of this standpoint.

2) In the *opening stage*, the protagonists and the antagonists in the dispute are identified. The protagonists undertake the obligation to defend the standpoint at issue, while the antagonists assume the obligation to respond critically to the standpoint and the protagonist's defense. In this stage, it is also certified that the protagonists and antagonists have sufficient common ground (shared background knowledge, values, rules). According to van Eemeren et al. (1996,282), it only makes sense to undertake an attempt to eliminate a difference of opinion by means of argumentation if such a starting point can be established.

3) In the *argumentation stage*, the party that acts as the protagonists methodically defends the standpoint at issue against critical responses of the antagonists. If the antagonist is not yet wholly convinced of all parts of the protagonist's argumentation, he or she elicits new argumentation from the protagonists, and so on. According to van Eemeren et al. (1996,282) there is no critical discussion if there is no argumentation or no critical appraisal of this argumentation.

4) In the *concluding stage*, the protagonists of a standpoint and the antagonists determine whether the protagonists' standpoint has been successfully defended against the critical responses of the antagonists. In the argumentative discourse, the concluding stage corresponds with the stage, in which the parties draw conclusions about the result of the attempt to resolve a difference of opinion. According to van Eemeren et al. (1996,282), the critical discussion has not led to a resolution of the difference of opinion if the parties do not agree on the outcome of the discussion.

The phases of the realized Argument Delphi exercises are similar to those of the above ideal model. The argumentation process in the study concerning the future impacts of the new biotechnology made in 1989-1990 (Kuusi 1991) has the stages discussed below.

The preliminary stage of the Biotech Delphi study was based on the work of an advisory board and Delphi managers. The advisory board included leading experts of the Finnish new biotechnology community. They were used for the preparation of the confrontation stage, though the ideas of the Argument Delphi were more tacit than explicit in the beginning of the Delphi process. The advisory board and Delphi managers define eleven preliminary issue areas of the new biotechnology. The study had three Delphi managers. One of the them does not belong to the Finnish developer community of the new biotechnology. Two others were its active members and doctors of biosciences.

The advisory board and the Delphi managers selected most of the 28 panelists of the study. Some further panelists were selected based on the first round interviews ("snowball sampling"). The panelists represented different points of view concerning the new biotechnology. They also had the basic expertise of the new

biotechnology. So the protagonists and antagonists of the argumentation process had a sufficient common ground for critical discussion.

In the first round, every panelist was personally interviewed by the Delphi managers. With a few exemptions, the interviews were made by the "outsider" of the biotech community (the author) together with an "insider". The interviews lasted 3-5 hours. The interviews were used to define the issues and topics. Beside this element of the confrontation stage, the first arguments of the argumentation stage were identified in the interviews. Experts were firstly asked to present promising Finnish products in the issue areas or the branches and their life-cycle stages in 1999 and 2010. They were asked to give factual arguments for their judgments and the Delphi managers presented the anonymous arguments of other panelists to them. Lastly, panelists were asked to evaluate the life-cycle stages of the whole branches in Finland 1999 and 2010 and their economic and social significance.

The second stage of the study was a clear counterpart of the argumentation stage. A rather extensive report concerning the first stage was mailed to the panelists. In the report, the arguments presented were formulated into issues including specified suggestions concerning the future (topics) and to anonymous arguments for or against the topics of an issue. Most of the suggestions explicitly or implicitly concerned new biotechnology generalization proposals. The issues were divided in the eleven issue areas or branches. Eight +/- 1 special experts were nominated for every branch. They were asked to evaluate the topics, mostly using simple "will be true in 1999 or 2010" or "will not be true in 1999 or 2010" reactions. Based on the interviews, the Delphi managers presented suggestions concerning the reactions of the experts. The experts were asked both to correct the suggestions and to give further comments on the topics and arguments.

The total number of issues discussed in the second round was 49, in addition to the general evaluations concerning the developments of eleven branches or issue areas. The total number of the topics was about three hundred. This means that the average number of topics in an issue was six. In reality, there were issues including only one topic and others with ten or even more topics.

The mailed report of the second stage included about 100 pages. It was divided in two parts for every single panelist. On average about 20 pages dealt with issues of his or her special expertise. The remaining about 80 pages dealt with the other issues. If the panelist so wished, he or she was also allowed to comment on the topics and arguments of other issues. Everybody was asked to correct their judgments concerning the life cycle stages, economic significance and social significance of all issue areas or branches in 1999 and 2010. As background information, the distributions of the evaluations of the other panelists were anonymously presented.



Beside special experts, typically 2-3 other experts made judgments and comments on the topics. Hence on average about 10 or one third of the panel reacted to any single topic. The second round of the study also had features of the conclusion stage. If two experts who presented different opinions in the interview stage were ready to accept a common conclusion, we might consider an issue or a topic to be resolved.

The argumentation and preparation of conclusions continued in the third stage. In the third stage of the study, a common seminar of panelists was arranged. The topics which produced disagreement were discussed based on the presentations of some panelists. Because a personal meeting destroyed the anonymity of the Delphi study, any changes of mind of the panelists were ignored in the final report. The comments were, however, useful in the evaluation of results. In the final stage, Delphi managers also asked those panelists who made major contributions to the study to comment on a preliminary version of the final report.

When we describe a Delphi process with the four process stages of van Eemeren et al. (1996) we are able to discern sufficient conditions for a *reasonable* resolution of the difference of opinions. The fact that protagonists and antagonists agree concerning a topic does not guarantee that the resolution is reasonable. Resolution is a necessary but not the sufficient condition for commitment reasonability because it may be based on the acceptance of irrational arguments.

Actually, a main target of the modern argumentation theory represented e.g. by van Eemeren et al. (1996) has been to increase the reasonability of the argumentation. The "Ten Commandments" of critical discussion introduced by van Eemeren and Grootendorst (1992, van Eemeren et al. 1996, 283-284) apparently include their answer to that question:

Rule (1) Parties must not prevent each other from advancing standpoints or from casting doubt on standpoints.

Rule (2) A party that advances a standpoint is obliged to defend it if asked by the other party to do so.

Rule (3) A party's attack on a standpoint must relate to the standpoint that has indeed been advanced by the other party.

Rule (4) A party may defend a standpoint only by advancing argumentation relating to that standpoint.

Rule (5) A party may not disown a premise that has been left implicit by that party or falsely present something as a premise that has been left unexpressed by the other party.

Rule (6) A party may not falsely present a premise as an accepted starting point nor deny a premise representing an accepted starting point.

Rule (7) A party may not regard a standpoint as conclusively defended if the defense does not take place by means of an appropriate argumentation scheme that is correctly applied.

Rule (8) A party may only use arguments in its argumentation that are logically valid or capable of being validated by making explicit one or more unexpressed premises.

Rule (9) A failed defense of a standpoint must result in the party that put forward the standpoint retracting it and a conclusive defense of the standpoint must result in the other party retracting its doubt about the standpoint.

Rule (10) A party must not use formulations that are insufficiently clear or confusingly ambiguous and a party must interpret the other party's formulations as carefully and accurately as possible.

In general, I consider that the above rules with the qualifications discussed below and in the next chapters provide reasonable basic rules for the Argument Delphi. *The implicit decision rule of the Argument Delphi is the model of the epistemic utility presented in the paragraph 3.4* The rules 1 -10 are basically in line with the epistemic utility model. This model gives sufficient conditions for the resolution of opinion differences concerning the realization of technology generalizations. Issues concerning technology generalization options refer to a specific type of question: *should some actors start a realization process or make further investments in the realization of a technology generalization option X?* The decision is based on the following rule: If the epistemic utility value IFVR of the option X is higher than the minimum limit value L for an actor, the answer is affirmative.

The first two rules of van Eemeren et al. concern the option reasonability of the argumentation. It is difficult to evaluate the validity or the reasonability of arguments if they are not known or if they are only expertise based proxy arguments of the factual arguments. A difficulty was discussed at the beginning of the paragraph 3.8. Rules (1) and (2) concern the option-suggesting arguments discussed in paragraph 3.5, which opens the discussion concerning the reasonability and especially the validity of an option. Rules (1) and (2) require that both the protagonists and the antagonists of an option make open their arguments concerning the "starting validity" of the option. It is based on original arguments concerning technical validity (I and F) of e.g. the referred similar technology generalization. The protagonists and the antagonists have also starting point arguments about the relevancy (R) of the option discussed.

Rules 3 - 8 try to ensure that the defense or the attack take place only by means of epistemic rational arguments. *A difference of opinions cannot be truly resolved with rhetorical devices, if decisions are made based on the epistemic utility. Arguments which violate rules 3 - 8 often impair the validity of the argumentation and so they impair also epistemic utilities of discussed technology generalizations.* Arguments presented by protagonists or antagonists in the Argument Delphi process should have positive impacts on the epistemic utilities of discussed generalizations of technologies.

The point given in rules (3) and (4) concerns the relevance of the arguments such as the second rule of Keekok Lee discussed in the first chapter. A difference of opinions cannot be resolved if the antagonist attacks and the protagonist defends different standpoints. According to van Eemeren et al. (1996,285), the rule (5) ensures that implicit elements within the protagonist's argumentation are also examined critically. A difference of opinions cannot be resolved, if a protagonist tries to withdraw from the obligation to defend an unexpressed premise. On the other hand, the rule (6) ensures that the starting points of the discussion are interpreted in a similar way. For the production of epistemic utility in the epistemic utility model, the rules are important because they are highly relevant for the evaluation of the validity of the options discussed.

Rule (7) is aimed at ensuring that the argumentation can lead to a reasonable resolution of a difference of opinions when a protagonist and an antagonist agree on a method of testing the soundness of arguments which are not part of the common starting point. The rule (8) concerns directly the validity. According to van Eemeren et al. (1996, 285) the reasoning is valid if the defended standpoint follows logically from the premises used (compare the third rule of Keekok Lee). I think that in practice, rules 7 and 8 are very difficult to meet in the discussions concerning future technology generalizations. Though there are arguments which all or at least nearly all experts can accept to be valid I think that instead of valid arguments it is reasonable to speak about more or less validated or rational arguments. The different paradigms of experts often result in different methods for testing the soundness of future options.

Rule (9) is aimed at ensuring that a protagonist and an antagonist ascertain in a correct manner what the result of the discussion is. According to van Eemeren et al. (1996, 285-286) a difference of opinion is truly resolved only if the parties agree in the concluding stage whether or not the attempt at defense on the part of the protagonist has succeeded. In reality, a technology Delphi argumentation process seldom results in the final resolution of an issue or a topic. Instead, it often results in a partial resolution of an issue, which can be described by the changes in the epistemic utility evaluations of experts.

Rule (10) is aimed at preventing misunderstandings. Problems in formulation and interpretations may arise at all stages of a discussion; they are not linked to any particular stage. In practice the differences in the paradigms of experts often result in misunderstandings.

The real process of the Argument Delphi can be understood in the light of above rules, the Epistemic utility model and the social psychological and the action theoretical points of view which will be discussed in the next chapters.

### 3.11 Fields, Issue Areas, Issues and Topics in Technology Delphi Studies

In the beginning of the previous paragraph, I mentioned that the Argument Delphi operates on four levels. Topics, issues and areas of issues were already mentioned. It is reasonable to classify areas of issues into *issue fields*. The distinctive feature of an issue field is that typically the same panellists are general experts in an issue field just as the same panellists are special experts in an issue area. The general expertise of a issue field does not mean that the expert knows details of the issue areas of the issue field. It is enough that a general expert can evaluate the validity of arguments of special experts.

I illustrate the general expertise with an example. Let a special expert in the issue area "Applications of new biotechnology in the forest industry" present the following argument: "Some kinds of enzymes can be used in the production of pulp to separate lignin and cellulose". It is not needed that a general expert knows exactly, how specific enzymes behave. It is enough that the general expert of the issue field "Biotechnology" knows that enzymes are typically big molecules and what are their catalytic functions in his or her own special issue area. It might be for example "Applications of new biotechnology in the production of medicines".

An evident counterpart of an issue field in national technology foresight studies has been a *field of expertise* in which an expert panel is collected. The fields of the national Japanese - German technology Delphi studies were (Cuhls et al. 1994, 16):

1. Materials and processing
2. Information and electronics
3. Life science
4. Space
5. Particles
6. Marine science and earth science
7. Mineral and water resources
8. Energy

9. Environment
10. Agriculture, Forestry and Fisheries
11. Production
12. Urbanization and construction
13. Communications
14. Transportation
15. Medical care and health
16. Culture and life styles

The above fields can be divided in science or technology push oriented and demand or need pull oriented. The six first fields are clearly technology push oriented and the fields 7 - 16 are more need pull oriented. My study Kuusi (1994) can be seen as a special study concerning the first field and the study Kuusi (1991) as a special study concerning the third field. From the point of view of an option-seeking technology Delphi study, a practical definition of an issue field can be given using the technological bonsai tree discussed in the chapter 2. An issue field can be described by the aggregate bonsai tree of the experts working in that field. *The aggregate bonsai tree includes those product branches and generic techniques which the experts in the field consider that their key competencies can connect for promising technology generalizations.*

If the research hypothesis of a technology foresight study concerning a field of expertise is given in the form of a hypothetical aggregate bonsai tree, an issue area obtains the following interpretation:

- a) How to use generic technologies of a "technology push" oriented field (or of the "roots" of an aggregate bonsai tree) to realize in different branches applications or products<sup>9</sup>; or
- b) How to solve different types of target related problems (of a product "branch" of the aggregate bonsai tree) of a "demand pull" oriented field using all kinds of technologies<sup>10</sup>?

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<sup>9</sup> The issue areas of the study Kuusi (1991) were e.g. Applications of the new biotechnology in diagnostics; Applications of the new biotechnology in the production of medicines; Applications of the new biotechnology in diagnostics; and Applications of the new biotechnology in forest industry.

<sup>10</sup> A "demand pull oriented bonsai-tree" can be interpreted to be "grown" around one application branch like the "Medical care and health" in the German - Japanese study. "Applications of the new biotechnology in the production of medicines" could be an issue area in this field. Even issues and topics of this common issue area might be identical with a technology push oriented field "New biotechnology". When in a technology push oriented field the variety of considered application branches is great, in a demand pull oriented field the variety of considered generic technologies is great. I consider, however, that recently important developer communities or "learning communities" are usually "technology or science push" oriented, because they have a common (scientific) paradigm. E.g. designers might, however, also have a common paradigm.

An issue describes a specific choice situation in an issue area. Topics can be seen as alternative futures in a choice situation<sup>11</sup>.

In the national technology foresight studies the levels of issues and issue areas have been unclear. The classifications have had three levels. All studies have had the level of topics and the level of “science push” or “demand pull” oriented fields<sup>12</sup>. The content of a level between these levels has varied. The topics have been classified e.g. into “sub-sectors” (Loveridge et al. 1995) or “divisions of topics” (NISTEP 1997).

Is the interpretation reasonable that the classes between topics and fields are areas of issues? Actually the subclasses have often not been real areas of issues focused on a special expertise area. In the last Japanese study the topics of the field Life Science were divided into “molecules”, “cells”, “tissues and organs”, “individuals”, “groups” (NISTEP 1997, 226-245). This Japanese classification of Life Science topics has very weak connections with issues or issue areas.

It seems that the sub-classification of “Life Sciences” of the German study is a compromise between very broad issues and issue areas. The field is divided into two main sub-fields: “Health” and “Life Processes”. The classes in the sub-field Health are more like broad issues than issue areas (Delphi '98, 138-163): “prevention”, “causes of diseases”, “diagnostics”, “therapy”, “health systems and services”, “ethics”, “information techniques”, though “diagnostics” and “therapy” can also be seen as issue areas, as in the author’s study Kuusi (1991). On the other hand, the division of the sub-field Life Processes was more like my division of issue areas: “genetics”, “reproduction”, “developmental biology”, “structural-functional relationships”, “evolution” and “biotechnology”.

The “Life Science” classification of the UK study (Loveridge et al. 1995, 338-353) is mostly focused on issue areas e.g. “Advances in Diagnostics and Instrumentation”, “Advances in Therapeutics”, “Cancer”, “Molecular and Cellular Sciences”, “Neurosciences and Cognition” and “Informatics” are more like issue areas.

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<sup>11</sup> The number of topics varied from about 40 to about 110 in one field e.g. in the common Japanese and German study (Cuhls and Kuwahara 1994, 16). In the UK study the number of topics in a field varied between 75 and 113 (Loveridge et al. 1995). When I compare this number of topics with the number of issues in the author’s studies (Kuusi 1991, 1994), the scope of topics in national studies has in average been nearly the same as the scope of issues in the author’s study. Topics of the national studies and issues of the author’s studies seem to have analogous scopes.

<sup>12</sup> This name has been used in the English translations of the Japanese studies (NISTEP 1997). The German name has been *der Themenfeld* (Cuhls et al. 1998). In the UK study the counterparts of fields are “sectors” (Loveridge et al. 1995).

A possible original reason for the lack of clear divisions based on topics, issues and issue areas seems to be connected with the original idea of prediction reasonability. When the first national technology Delphi study was made in Japan in the beginning of 1970s, the "state of art" was to make long term predictions. Like the famous study of Gordon and Helmer (1964), which was called long-range forecasting study, most technology Delphi studies discussed by Sackman (1975) were used for the timing of events. Will an event be true or will it not be true in some future date?

As was discussed above the topics in the Japanese Delphi studies are now in practice more than events options ("miniscenarios") or issues related to futures. Cuhls (1998) who has made comparisons with Japanese and German national technology Delphi studies has even interpreted topics as sub-targets. The "transformation" of topics from possible future events to options or issues is related to the increasing use of proxy arguments related to the topics. A kind of "end" of this transformation is visible in the Austrian national foresight study (Delphi Report Austria 1, 1998). In this study it was not even asked the period of time, when a topic will realize.

The Austrian study had a three-level classification: "Themenbereichen", "Fachgebiete" and "Thesen". The first class is the clear counterpart of the fields of issues (or fields of general expertise). "Fachgebiete" are counterparts of issue areas (or areas of special expertise). "Thesen" have features of issues<sup>13</sup> or more specific technology generalization options (topics in my classification)<sup>14</sup>. Their realization is evaluated based on some possible means ("Massnahmen") "Massnahmen" are more than "proxy arguments" they are standardized factual arguments. They suggest what government or some other actor might do in order to realize a topic using standard means<sup>15</sup>. Instead of factual arguments discussed in the paragraph 3.5. we have information concerning standard means and the importance evaluations of experts concerning these means. In a way a target hierarchy based on topics is connected to a hierarchy of means. A similar idea was used in "a coordinative method for social policy target programs" in 1970s (Kuusi 1979).

There is surely no single right way to make an Argument Delphi exercise. If one decides to use a large Delphi panel, the evaluation of standard arguments as in the Austrian exercise seems to be a reasonable choice. If one decides to work in-

<sup>13</sup> E.g. "Neue Therapien (z.B. verbesserte Enzym-, Rezeptoren- und Mediatorenblocker) werden zur Bekämpfung altersspezifischer degenerativer Erkrankungen wie M. Alzheimer, Cardiopathien und Arteriosklerose eingesetzt" (Delphi Report Austria 1, 1998, 70)

<sup>14</sup> E.g. "Die Transplantation von organoide Material (z.B. Implantation von dopaminproduzierenden Zellen aus Foeten) wird zur Therapie des M. Parkinson eingesetzt." (Delphi Report Austria 1, 1998, 70)

<sup>15</sup> E.g. "Immunologische Forschung fördern" (Delphi Report Austria 1, 1998, 80)

tensively with a small panel, the author's studies (Kuusi 1991 and 1994) seem to have reasonable features. I will next discuss some special features of the author's studies in order to illustrate problems of practical Argument Delphi processes.

A common praxis in the defining of topics in the national technology Delphi studies has been the use of work groups. E.g. in the Austrian study, the job was done by field panels of 14-23 members. I think that this is not an optimal procedure for the option reasonability because, based on the lack of anonymity, it might result in conventional choices of topics. In the first rounds of author's Delphi studies, issues and topics were produced based on the interview discussions concerning issue areas. The defining of issues and topics was based for example on the following question (Kuusi 1994):

What kinds of products will be made in 2010 using the basic generic technologies of the new material technology in the area of construction?

The interviews made it easy to proceed to more subtle aspects of issues or possible technology generalizations. It was also easy in an interview to stimulate consideration of the otherwise neglected arguments by interjecting comments for consideration. "Stupid questions" were useful because the best experts in technologies are often not very innovative. They tend to continue existing development processes (e.g. Schrum 1985).

In my option-production focused study, finding of relevant issues and topics was a main task of the experts. It is vital that issues and topics are not too general or not too specific and that the conceptual frameworks of the panellists and the customers of the studies have been taken into account. Otherwise, the epistemic value of the argumentation concerning a topic might be small. An example of a topic concerning the issue of the Diagnosis of Hereditary Diseases in the study Kuusi (1991) is the many times discussed suggestion:

*In 1999, the fetuses of all pregnant women in Finland who give their consent will be examined for at least three hereditary diseases with new methods, either for a small remuneration or no remuneration at all.*

After the specification of the issue and its topics, the standpoints of the experts concerning each issue were asked. In the extensive Japanese and German Delphi studies, many types of standpoints were asked as was discussed above. As I pointed out above, the different types of standpoints ("proxy arguments") have actually substituted factual arguments. I used to ask the panelists to take a standpoint concerning a topic in a very simple way: does the expert accept or reject the development suggested by the topic?



In the study Kuusi (1994) the expert was, however, asked to make a further evaluation concerning the general point of view from which he or she looks at any specific issue. Hence, the experts selected whether they liked to look at the issue from the point of view of prediction, commitment or option reasonability. One point of view (A, B, C or D) was suggested for every topic and an expert was allowed to change the proposed point of view. The points of view were as follows:

A. The onlooker point of view. The possible developments are anticipated, putting one's own interests aside. The probable developments are sought.

B. The point of view of the maker of the future. Future options are sought whose realization is reasonable. The focus is on the allocation of resources without taking too much or too little risk.

C. The point of view of providing for bad alternatives or seeking minmax options.

D. The point of view of finding good but insecure options or seeking maxmax options.

Point of view A is clearly focused on prediction reasonability. This point of view was suggested if the actions of panelists or customers of the study were judged to have no or very little impact on the issue. This situation was assumed to prevail in most generalization processes of technologies where foreign actors dominated. Though the predictive reasonability was the suggested point of view in these issues, accurate predictions were still not the main focus of interest. The "will happen - will not happen" decisions were requested more to provoke further arguments and to make judgments based on the factual arguments presented.

The suggested point of view was B if it was considered that the panelists or customers of the study would have a considerable impact on it. In that case, the commitment reasonability is an important point of view, though the production of new arguments was also an important target in these cases.

If the suggested point of view was C or D, it was considered, that it was impossible to make any final conclusions concerning the prospects of the topic with the present information. In this situation option reasonability clearly dominates in the argumentation and the making of judgments.

The panelists did not have to accept the suggested point of view concerning a specific issue. I will later discuss how the panelists in reality reacted to the suggested points of view.

### 3.12 Different Types of Reasonability in a Prediction-Oriented Delphi Study

A Delphi study was made in 1976 which anticipated 24 communication trends and 17 events in the State of Hawaii over a 30-year period. Ryota Ono and Dan J. Wedemayer (1994) evaluated the results of that study with a new study made in 1992. The expressed purpose of the study of Ono and Wedemayer (1994, 291) was predictive validity: whether or not the 1976 forecasts for 1991 were accurate.

Though the expressed main target of the study was predictive reasonability, other two types of reasonability were also clearly present in the studies. Option reasonability was sought in the 1976 study, as in many other prediction-oriented studies already before the expert panel was used. An option-reasonability-oriented phase was the selection of the potential items in the questionnaires. They were drawn from "various communication, social and psychological theories and frameworks" (Ono and Wedemayer 1994, 291). The extensive list of events and trends was then subjected to the following two criteria for inclusion in the study:

Event questions:

- a) Is the event likely to occur within the next thirty year?
- b) Is the impact of the event significant to communication in the state of Hawaii?

A selected event was e.g. "The establishment of the first video conference center in the state". This can clearly seen to be a generalization proposal of the generic techniques of the new communication technology.

Trend questions:

- c) Is there a strong likelihood that any of the discussed levels of a trend - the level of the need, the level of the supply or the right level (see below) - will deviate from the anticipated level?
- d) Will there be a direct or indirect impact on communication in general if the deviation occurs?

A selected trend was e.g. "Mobile communication: Ability to communicate without being stationary". The definitions of different levels were given as follows:

*Need level* or baseline communication needs: The level required for society to function without experiencing urgency, privation or destitution. It is neither the minimum nor utopian level; it is something between these extremes.

*Supply level* or available communication supply: The means, technology, and/or personnel availability at a particular time period to serve communication needs.

*Right level* or strength of communication right: The intensity of that which is due anyone by just claim, legal guarantees, moral principles, etc.

Two interpretations concerning the epistemic roles of the criteria a-d are possible. Perhaps the more plausible interpretation is that criteria a) and b) functioned in similar roles to my two necessary conditions of predictive reasonability. If an event is anticipated to happen, it presupposes an anticipation that relevant actors are successfully active or  $I_b \times F_b \times V_b \times R_{bA}$  is over  $L_A$ , where A is the group of actors whose actions are decisive for the realization of the generalization b. Criterion b) can be interpreted to be just a more concrete way to express my second condition.

Another interpretation is that the selected events and trends were interesting from the viewpoint of the Delphi managers or some decision makers. According to this interpretation, the option reasonability was still the main focus in the selection phase and the predictive reasonability was sought only in the next phase, where the expert panel was used.

In the selection of trends for the 1976 Delphi study, the main criterion was the evaluated invalidity of anticipation based (linearly?) on past developments (or using the concepts of the GTC on transient invariances). This selection criterion is at least vaguely connected with the anticipated surprise or the newness values of the expert evaluations. Assuming that this criterion is fulfilled c) and d) have similar possible interpretations to a) and b).

The Delphi panel of the 1976 study was selected in the following way (Ono and Wedemayer 1994, 291). I will present the selection process of the panel in details because it is interesting for forthcoming discussion of the selection criteria of the expert panel:

Initially, 500 communication specialists were identified by using Hawaii communication conference attendance lists and professional directories compiled during the previous three-to-five years. From these 500 specialists, 70 experts were selected by a panel of four professional communication specialists, in terms of their notable experience, knowledge or special skill in the field of communication, and such balancing factors as island location, sex, race, technical, social and political orientation. Of the 70 experts, 60 respondents agreed to participate in the study. These experts were matched into pairs on the basis of their responses to self-rating forms about their expertise in eco-

nomics, politics, culture, psychology, technology and sociology, and then were randomly assigned to one of two Delphi panels.

In the 1992 study, two panels were formed: the experts of the year 1976 panel ("old panel") and a new control panel ("new panel"). The roles of the panels in the 1976 study and in the 1992 study were to make different types of predictions concerning the selected events and trends. The epistemic nature of the predictions of events was clearly predictive reasonability. The 1992 panels simply evaluated whether the events anticipated in 1976 to happen before 1991 had really happened.

The reasonability of trend evaluations sought also includes, however, features of the commitment reasonability. One object of the prediction was the Policy Urgency Index (PUI), which Ono and Wedemayer (1994, 293) used to indicate the urgency of policy formulation or planning vis-à-vis each individual trend. It was derived as follows:

$$\text{PUI} = (\text{Need level} - \text{Supply level}) \times \text{Right level}$$

The 1976, the Delphi panelists were asked to evaluate every discussed trend on the three levels of the PUI-index for 1976, 1991 and 2006. The evaluation scale of every variable was 0-100 (from "none" to "absolute"). The values of the PUI-indexes in the year 1976 study concerning the year 1991 were compared with the PUI-indexes, which were got from the repetition study. What was the type of epistemic reasonability of the PUI-indexes?

The difference between need value and supply value describes an imbalance between demand and supply. A (probably too) simple explanation of the gap between demand and supply is that the price of the communication commodities described by the discussed trend is not on the right place to eliminate the difference between supply and demand. The problem evidently concerns not only reasonable pricing. The PUI-index concerns not only the gap between present demand and present supply, but between some rational future demand and anticipated future supply.

Only the anticipation of the Supply level can be seen as prediction-reasonable activity. The evaluation of the Need level and the Right level are based on commitment reasonability. Let us use the concepts of the GTC. Panelists are not asked to evaluate the future perceived capability limits (or real/ true demand in the future). By definition the Demand levels and the Right levels refer to reasonable "real" capability limits. They are reasonable equilibrium points of learning processes or choices of "enlighten" citizens, as they were perceived by Delphi panellists.

My conclusions give an interpretation of the results of Ono and Wedemeyer. They compare the rankings of different indexes of the old panel in 1976 and 1992 and the new panel in 1992. The statistical significances of the rank correlations between rank evaluations in 1976 and 1992 were (highest at the top) as follows:

PUI-indexes of the old panel 1976 vs. 1992 (significant in  $p < 0.05$  level )  
 Need-indexes of the old panel 1976 vs. 1992 (significant in  $p < 0.05$  level )  
 PUI-indexes of the old panel 1976 and the new panel 1992 (significant in  $p < 0.05$  level)  
 Right value-indexes of the old panel 1976 vs. 1992 (significant in  $p < 0.05$  level )  
 Need-indexes of the old panel 1976 and the new panel 1992 (significant in  $p < 0.05$  level)  
 Right value-indexes of the old panel 1976 and the new panel 1992 (not significant positive correlation)  
 Supply-indexes of the old panel 1976 and the new panel 1992 (zero correlation)  
 Supply-indexes of the old panel 1976 vs. 1992 (not significant negative correlation)

Old experts had not radically changed their minds in what are commitment reasonable choices (Need indexes and Right value-indexes). On the other hand the predictive reasonable element of the PUI-index, the supply side, had not developed as they anticipated in 1976. This conclusion is reinforced by the evaluation of the new panel. It was interesting that the opinions of the whole expert community and not only of the old panelists had remained rather stable concerning commitment-reasonable demand.

The final conclusion of Ono and Wedemeyer (1994,300) that the Delphi technique is a valid technique for long-range forecasting is very questionable as far as it was based on the rank correlation of the variables of the PUI-index. A better conclusion is that the opinions of experts concerning the commitment reasonability had remained rather stable though supply conditions did not develop as anticipated in the period 1976-1991. This means that the prediction reasonability of the 1976 study was rather poor concerning the trends. The prediction reasonability of the 1976 study concerning the events was, however, better. The predictions of five events out of nine events concerning 1991 were accurate, based on the evaluations made in 1992.

### **3.13 Commitment-Oriented Delphi Study: the UK Program**

#### **3.13.1 The objectives of the UK Program**

Commitment has been a very important objective of recent large technology foresight Delphi studies. An example is a study made by the International Standardization Organization in 1989. In this study, a total of 2744 replies were received from 40 countries (A Vision ... 1990). Standardization needs the commitment of the worldwide developer communities of technologies.

Commitment strategies of national or international developer communities of technologies vary. Cuhls (1998, 128-130) made an interesting empirical conclusion concerning commitment strategies of the Japanese and German developer communities based on the common Delphi study of Japan and Germany in the beginning of 1990s. In average if Japanese experts evaluated that Japan was not in a good research position concerning a topic, they preferred international cooperation. No such a relationship is visible in the evaluations of German panellists, which also in general preferred international cooperation more than Japanese panellists.

The development of national innovation systems needs the commitment of technology communities, e.g. for setting priority areas for national programs of technology development. The United Kingdoms Technology Foresight Program has stressed this point.

Like the German Delphi studies discussed above and the study made by the International Standardization Organization, an important starting point of the UK Programme has been the Japanese studies. However, it was never intended that the use of Delphi in the UK would entail a further iteration of the Japanese questions. These were considered to reflect the agenda of Japanese industry and scientists and would not necessarily correspond to the specific aims of the UK Programme. The specific objectives of the UK Delphi study were (Loveridge et al. 1995, 5) as follows:

- to access the business and science and technology communities' views on future developments in markets and technologies;
- to assist in achievement of commitment to results and consensus on developments; and
- to inform the wider business and science and technology communities about the major issues being addressed in the Technology Foresight Programme and how their peers assess those issues.

The objectives emphasize the interactive approach. According to Loveridge et al. (1995, 5): "As well as the most obvious function of gathering opinions for the Panels, the Delphi survey also aimed to involve large numbers of experts who would otherwise be excluded, and hence to widen significantly the constancy of participants feeling ownership of the results and a consequent commitment to their implementation". The program aimed to forge a new working partnership between scientists and industrialists best placed to assess emerging market opportunities and technological trends, and to inform decisions on the balance and direction of publicly funded science and technology (Georghiou 1996 p. 361). This commitment reasonability is very clear in a later definition of the three basic objectives of the Program (Science shaping... 1997, 1):

- it was intended to build a consensus on the various generic technologies which are likely to yield the greatest economic and social benefits to the UK in the long term;
- it was designed to break down barriers between different parts of the UK and its institutions (between industry and academia; between the City and high-tech industry; between markets and technologies);
- it was also meant to influence the funding patterns of publicly-funded research
- through the Office of Science and Technology directly, via the Research Councils, via universities, via government departments, within industry and research and technology organizations.

Based on the above three objectives, the UK Delphi was focused on commitment reasonability. The third objective given in the main report (Loveridge et al. 1995), however, concerns option reasonability. The report motivates the third objective as follows: "Receipt of the questions gives the respondents early feedback on the topics deemed to be of interest by their peers on the Panels". This motivation is clearly given in the spirit of option reasonability.

A more extensive typology of the objectives of this technology foresight study was given in another document (UK Technology... 1994, 23-24). The specific objectives were divided in two groups:

**The process** was designed to

1. Break down barriers and create contacts/ networks between academia and industry, between small and large companies, between sectors and so on.
2. Help develop a consensus of future technological scenarios and their likelihood and importance.
3. Raise awareness among the science and technology community (both in the science base and industry) of the long-term potential of areas of technology and markets.

The process has also been characterized in terms of requiring delivery of "the five Cs" originally presented by Ben Martin (e.g. Martin 1996) which are:

4. Communication
5. Concentration on the longer term
6. Co-ordination of the research plans of the relevant actors
7. Consensus on the future directions and research priorities
8. Commitment amongst those responsible for developing and translating research results into benefits for society.

The **output/results** can be used to:

9. Identify particular generic technologies which are likely to be important to meeting societal goals over the next decade or so.
10. Identify fields and targets regarded as important in the long-term (up to 30 years).
11. Set priorities within broad fields of technology (e.g. between IT or biotechnology).
12. Set priorities between broad fields of science and technology (e.g. between biology and engineering).
13. Identify fields of "technological fusion" which may otherwise be overlooked because they fall across or between administrative or disciplinary boundaries.

These objectives of the UK technology foresight study are related to the three possible types of reasonability of the Delphi studies. The objectives 2 and 8 are closely linked with the prediction reasonability. The objectives 3, 9, 10 and 13 require the production of new options based on generic technologies and are thus linked with option reasonability. The objectives 1, 4, 5, 6, 7, 11 and 12 advance the coordinated actions of members of the technology community and require the commitment reasonability.

The key commitment-oriented objective of the UK study was priority setting for technology policy. The criteria in the priority setting of technologies (or technology generalizations) were divided further (Science Shaping...1997, 3):

1. Potential economic and social benefits
2. Opportunities for innovative science, engineering and technology
3. The ability of the industrial and institutional base to capture economic and social benefits
4. The ability of the science base to assume a leading position
5. The cost of supporting science, engineering and technology
6. The time required for the technology to mature.



### 3.13.2 The phases of the UK Program

I will next go through the phases of the UK program and evaluate them based on the framework given in this chapter.

The UK Program was very much based on the work of Panels including about ten persons in fifteen areas. Normally chaired by a senior industrial manager, the membership of these Panels was designed to draw upon a broad range of expertise (Loveridge et al. 1995,4). Following the Pre-Foresight phase, Panels generally began to meet in May 1994.

According to Loveridge et al. (1995,5) early emphasis was upon defining their scope and agendas, construction of scenarios and initial consultation on which issues should give consideration. The result of this activity was the identification of the areas of principal interest or the identification of the issue areas using my terminology. The identification of topics was assisted by a postal exercise targeted at 50-80 experts per Panel. Known as the 'Trends, Markets and Technologies Questionnaire', this requested respondents to follow a 'logic chain', whereby they answered the following linked questions (Loveridge et al. 1995,8):

- (i) List four trends or issues and their driving causes, that you believe may influence the sector up to 2015;
- (ii) Identify possible new market opportunities arising from trends or issues and driving causes;
- (iii) Identify possible new products, processes or services to meet the needs of some of the market opportunities; and
- (iv) Identify technologies, breakthroughs, scientific advances or innovations needed to underpin products, processes or services.

Typically, Panels found that the broader group of experts confirmed their own views rather than extending the agenda significantly. When compiling topics for the Delphi, there was normally a substantial surplus of candidate topics. Panels were given a maximum amount of freedom to formulate Delphi statements in their own way. Offered a suggested range of 50-80 topics, all the Panels tended to the maximum.

This list of questions or the criteria i-iv clearly indicate that "topics" of the UK study have the features of both the issues and the topics in the four level classification of the Argument Delphi. The criteria define a way to identify promising options. Using my conceptual framework, the results of this stage are option-suggesting arguments. What is the relationship between the criteria i-iv and my criteria of promising options?

We might assume that trends or issues identified by experts (the criterion i) used not to be separate interesting developments. Their potential importance is based on technological paradigms realized by the experts. It was interesting that the Panels considered that the broader group of experts used to confirm their own views. Perhaps a reason was that the Panel experts evaluated the suggested options based on their own technological paradigms.

The criteria ii-iv include the elements of my epistemic utility model. The criterion (ii) describes the impacts (I) and their relevancy (R). The criterion (iii) describes the feasibility (F) of some techniques to produce impacts resulting in new products, processes and/or services. The criterion (iv) is focused on realized invariances. It is reasonable to conclude that its main function is to produce arguments which increase the validity of the suggested I, F or R of the options.

The option identification stage resulted in topics or "Delphi statements" (Loveridge 1995,8). According to the report, "A Delphi statement must be a concise expression of the event, achievements or other phenomenon upon which views are sought." As in the Japanese studies, the following classification of the stages of innovation process was used:

*Elucidation*: to scientifically and theoretically identify principles or phenomena;

*Development*: to attain a specific technological goal or complete a prototype;

*Practical use*: the first practical use of an innovative product or service;

*Widespread use*: significant use: significant market penetration to a level where a product or service is in common use.

Half of the all topics concerned "widespread use" and only 2% were on "elucidation" in the UK study. In the fifth Japanese study, "widespread use" accounted for 21% and "elucidation" for 8%. This indicates the commitment-reasonability orientation of the UK study.

Selection of the panel of the main study was based on a co-nomination process, where "core panelists" suggested further experts. A problem of this process is the difficulty of identifying the challengers of the dominant paradigms. Further more, the experts on impacts (I), and the feasibility (F) of options are often not experts on the relevancy (R) of options. The main report of the UK study realizes the fact that the results of the co-nomination process might be biased: "To avoid excessive homogeneity, referred to above, the database should, in future, record the age and gender of the individuals" (Loveridge et al. 1995, 539).

The topics were evaluated in the manner of the Japanese and German national Delphi studies focusing on the judgments (or "proxy" arguments) of panelists. The dimensions of the proxy arguments were similar to those used in the Japanese and German studies (Loveridge 1995, 10-12): degree of expertise, degree of impact, period within which the event/development will have first occurred, necessity of collaboration, UK current position versus other countries and constraints on occurrence.

There were, however, some interesting differences. Instead of the importance of a topic, the evaluation was focused on the degree of impact of the topic on wealth-creation and on the degree of impact on quality of life<sup>16</sup>. Though this classification, like "the importance", does not make a clear distinction between the impacts and their relevancy evaluations, it is clearly a better proxy of that distinction than the "importance". The market value or the impact on wealth creation can be seen as a proxy indicator of the "objectively perceivable" impacts (I). At least in some cases, it is possible to measure the market value of a technology generalization proposal with relative objectivity, though all important objective impacts like measurable impacts on health do not have market prices. On the other hand, the impact on the quality of life can be seen as a proxy indicator of the (subjective) relevance.

The time schedules of the UK study were extremely demanding and not feasible for the factual argumentation of the panelists. The first round forms were dispatched by post in the beginning of September 1994. Second round forms were dispatched by post in the beginning of November 1994. In each round, a comments space was provided next to statement in which respondents were invited to amplify their responses. A fundamental difference between the Argument Delphi and the UK study was, that the very short interval between the two rounds made it unfeasible to feed a digest of these comments back into the UK second round survey (Loveridge 1995, 12). Besides the short lag between the rounds, very little time was provided both for the preparation of the forms and the analysis of the results.

### **3.13.3 Evaluation of the results of the UK study**

The participants of the UK Delphi were asked to evaluate the study. The responses of the panelists were summarized as follows (Science Shaping, 1997, 12):

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<sup>16</sup> This distinction was used also in the German-Japanese Mini-Delphi (Cuhls et al. 1995) and in later Japanese and German exercises (NISTEP 1997, Cuhls et al. 1998).

- 1) A majority believed Delphi to have been too complex, to have contained too many statements and variables, and to have offered too little time for the completion.
- 2) Others felt that sufficient expertise was already present within Panels to carry out the program effectively, and that the wider consultation objectives of Delphi could have been achieved via workshops, or expert hearings. E.g. regional workshops received a much more positive response.
- 3) Some saw the Delphi as a very cumbersome process producing very little new.
- 4) The co-nomination process is not effective in identifying other than "obvious" names. Less formal nomination processes used in Japan worked better.
- 5) More subgroups were favored.
- 6) More cross-over in membership was favored.
- 7) It was felt that small and medium size enterprises were a neglected sector.
- 8) The survey was too close to the panel report deadlines so that the panels had no time to absorb results.

The first and the last comments criticize the too hasty process, which made it difficult both for the panelists to produce relevant judgments and for the Panels to use them. This is especially apparent concerning factual arguments. Concerning comments 2 and 3, we might ask if it is really so that direct discussions in small working groups or in regional workshops could provide better opportunities for a national development program (for the commitment of expert communities) than the anonymous hearing of a large group of experts concerning many topics? Let us look at this question from the point of view of the characterization of commitment reasonability. It is possible to evaluate the results concerning any topic  $b$  of the study based on the following two criteria:

- (4)  $I_b F_b V_b R_b A$  is reasonably over  $L_A$ , where  $A$  is the group of actors whose actions are decisive for the realization of  $b$  or (4')  $I_b F_b V_b R_b A$  is over  $L_A$  (not necessarily reasonably), where  $A$  is a group of actors whose actions are decisive for the realization of  $b$ . It is possible for the group of customers of study  $B$  to make  $A$  commit themselves to actions which result in the realization of  $b$ .
- (5)  $I_b F_b V_b R_b B$  is reasonably over  $L_B$ , where  $B$  is the group of customers of the commitment producing study

The next conclusions are very preliminary and only try to show how the framework of the epistemic utility model might be used.

If only a small Panel of about 10 persons is used for judgments concerning 70 relevant topics (or issues) in a field and especially if it is not possible to see the real factual arguments on which the judgments of the Panel are based, it is very difficult to decide whether a real commitment of whole developer communities have happened (compare also with the comments "more subgroups were favored" and "it was felt that small and medium-size enterprises were a neglected sector"). It is very likely that the Panel in some way tries to manipulate the whole developer community in the field (the use of (4') instead of (4)).

On the other hand, the commitment reasonability might increase if the Panel or regional discussions produce new relevant rational arguments having an impact on  $I_b F_b V_b R_b$  of A or B. The less obvious names might be especially good in this sense (compare the comment "less formal nomination process used in Japan worked better").

The UK study at least partly met its commitment objectives. It resulted e.g. in a useful classification of issue areas for the priority setting. The Steering Group of the UK technology foresight program grouped 15 sectors into (Science Shaping...1997, 3):

- Sectors where the sectoral driver was primarily new advances and investment in basic science, engineering and technology (chemicals, materials, defense and aerospace, health and life-sciences);
- Sectors where the key driver will be the UK's ability to exploit foreseeable advances in science and technology and international access to products and services ( information technology and electronics, communications, food and drink, financial services);
- Sectors where key drivers are the political, social and regulatory environments (transport, energy, retailing and distribution, agriculture, natural resources and the environment);
- Sectors where advances will be due primarily to investment in human resources
- by developing new skills and deepening the understanding of business processes and consumer preferences, as much as by investment in relevant areas of science, engineering and technology (manufacturing, construction, leisure and learning).



## **4. SOCIAL INTERACTION IN THE DELPHI PROCESS AND THE VALIDITY AND RELEVANCE OF TECHNOLOGY FORESIGHT ARGUMENTATION**

### **4.1 Social Interaction in the Delphi Process and the Validity of Arguments or Judgements of Experts**

All the basic features of the Delphi method are ways to influence the communication process between panellists or between panellists and Delphi managers:

- Anonymity. The panellists do not know exactly who has produced an argument, though information may be available about some features of the producer of the argument.
- Iteration. There are several rounds for verbal argumentation or for making quantitative or qualitative judgements. The purpose of the iterations is to give possibilities for panellists to change their minds.
- Feedback. The anonyme judgements (quantitative or qualitative) of other panellists or further arguments are sent back to some or all panellists.

In this chapter, I try to answer the following question: Production of the arguments or judgements about the future is based on a social interaction process between Delphi panellists and Delphi managers. How can the interaction process increase or decrease the validity of arguments or judgements?

Let us look at a basic situation faced by any panellist many times during a Delphi argumentation process. This is a situation in which a panellist has to evaluate alone an argument or a judgement presented by a Delphi manager or another panellist in the light of the other arguments and judgements presented by other panellists. Two forces have an impact on the panellist's evaluation: M or the possibly "expertise weighted" median or average answer of the panellists; and T or the "truthlike" or directly validated value which seems to be reasonable based on the arguments known by the panellist before the study and based on the information content of the arguments presented by the other panellists (Parente et. al. 1987, Rowe et al. 1991, 247).

The production of arguments which can be directly evaluated as true, for example based on the reliable statistics or other reliable observations is an obvious way to produce valid arguments in a Delphi study. Because of the tacit knowledge of experts it is, however, reasonable to use expert judgements as proxy evidence. Judgements can also be catalysts for finding relevant new valid factual arguments and connections between actors.

The catalytic role of Delphi argumentation has received relatively little attention in the theoretical literature concerning the Delphi method, though its practical importance is now widely accepted.<sup>1</sup> Instead, a much discussed topic in the theoretical literature concerning the Delphi method has been: may the presentation of the average expert judgements or opinions improve the validity of argumentation of separate experts?

A main result of empirical studies has been that the "expertise-weighted" median or average answer of the panellists (M) is a rather questionable basis for the validity of judgements. The logical interpretation of M is *ad verecundiam* or appeal to authority: something is true (conclusion), because experts consider so (premise). Woods and Walton (1982, 86) considered that there are five necessary conditions for the plausibility of an appeal to authority.

- 1) The authority must be interpreted correctly.
- 2) The authority must actually have special competence in an area and not simply glamour, prestige or popularity.
- 3) The judgement of the authority must actually be within the special field of competence.
- 4) Direct evidence must be available in principle.
- 5) A consensus technique is required for adjudicating disagreements among equally qualified authorities.

A problem in the list is that the evaluation of the Delphi technique is at least partly in a vicious circle: Woods and Walton (1982) explicitly motivated the fifth condition by referring to the Delphi technique. As a motivation of the fourth condition, an example was given where an expert falls well outside the range of consensus of an expert panel. Woods and Walton suggested that a dissident has to argument for his or her standpoint, like in traditional Delphi studies.

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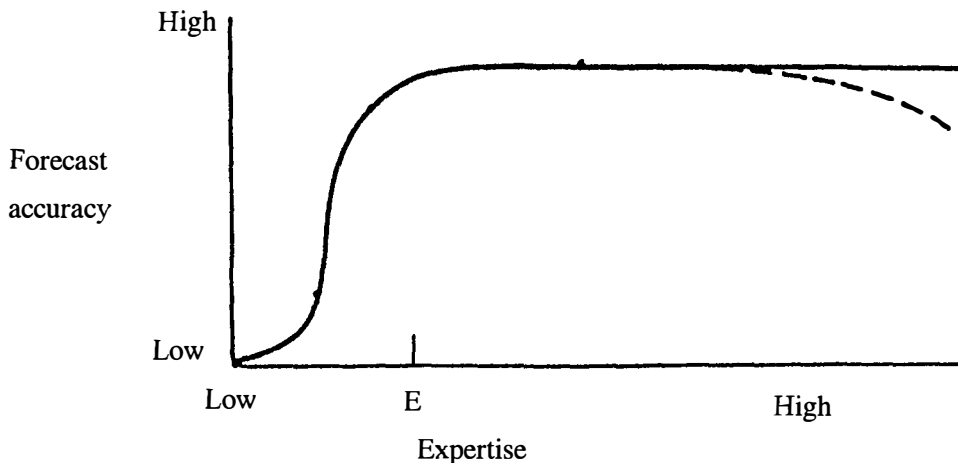
<sup>1</sup> In a recent article of Ben Martin and Ron Johnson (1999, 44) describe this function as follows: "Technology foresight offers a means of "wiring up" and strengthening the connections within the national innovation system so that knowledge can flow more freely among the constituent actors, and the system as a whole can flow more freely among the constituent actors, and the system as a whole can become more effective at learning and innovating.. Such learning requires a process for stimulating, nurturing, encouraging, and strengthening interactions between the actors so that the linkages between them become more permanent."



Amstrong (1985, 92) concludes the results of many "M-based " judgmental studies (Amstrong 1985, 93-96) as follows:

Many studies have been done on the value of experts. Most have come from psychology and finance, but there is evidence also from economics, medicine, sports and other areas. Expertise in the field of interest has been measured in various ways (education, experience, reputation, previous success, self-identification). Accuracy has also been measured in many ways. With few exemptions, the results fall into the pattern illustrated in the figure (figure 4.1). Above the low level of expertise labelled  $E_1$  (which can be obtained quickly and easily), and expertise and accuracy are almost unrelated.

*Figure 4.1. Relationship between expertise and accuracy in forecasting change*



A typical study cited by Amstrong was a study where, 24 PhDs, 24 trainees in psychology and 24 naive subjects (undergraduates) listened to 10-minute interviews with each of three clients and then predicted how each client would fill out three different personality inventories. There was no difference in accuracy between the PhDs and the trainees, and both were significantly more accurate than the naive subjects.

Based on the present state of the art, one can hardly rely on the predictive validity of "M-based" expert judgements in technology foresight studies. I consider, however, that in the future, expert judgements may be an important source of valid information. The conclusion of Amstrong is a typical example of a too straight-forward empirical conclusion based on the lack of a real explanatory theory. It is like the following conclusion:

It is perceived in many studies that objects (compare the judges of future developments!) fall at different velocities. The conclusion is that the properties (compare the expertise!) of objects do not have a significant impact on their velocities.

We do not know if there is powerful theory about how to eliminate the biases of the past expertise-based judgements in the anticipation of future generalizations of technologies. Though it seems to be very difficult (perhaps impossible) to find a relevant theory working in all situations, I consider that the epistemic starting points of the GTC and the epistemic utility model discussed in the previous chapter may be useful in this context. Let us suppose that we have found a relevant theory. In that case, it is clear that an expert knowing the theory, the expert judgements and the needed background information concerning the experts required by the theory, would be a better expert about the future than an expert or a naive subject who does not know the theory and the relevant past evidence. Analogously, the astronomer who knows the relevant laws of nature and relevant properties of planets is obviously a better forecaster of the future behaviour of planets than an unqualified astronomer or a naive subject.

A remarkable attempt to devise a relevant general framework for the critical examination of expert information is the "factor model" presented by Fjermestad, Hiltz and Turoff (Hiltz and Turoff 1995, 486-501). Though this model is clearly a remarkable achievement, it has a basic weakness: it is too complicated to be very useful. It is more a loose collection of theoretical concepts from different sciences than a real compact theory. It is more a way to describe research problems or a way to classify problems than a way to solve them.

The concepts used in the "factor model" to evaluate the validity of argumentation originate from the history of philosophy: inductive ("Lockean"), deductive ("Leibnitzian"), relative ("Kantian"), negotiated ("pragmatic") and conflictual ("Hegelian"). The concepts used to evaluate the complexity of problems can be seen to be an application of the Kuhnian idea of paradigmatic and preparadigmatic sciences: structured, semistructured, unstructured and wicked problems. Members of expert panels are characterized according to the conventional psychological concepts: attitudes, values, power, self confidence, demographics, interpersonal skills, initial quality. What happens during the interaction process of experts (during "the adaptation process") is also described using the conventional psychological concepts: level of effort of experts, emergent structure of communicating group, emergent leadership, diffusion of responsibility, deindividuation, pressure to consensus, co-ordination, co-operation and structuration. The "outcome factors" are measured in so many dimensions that it is really difficult to see the point of measurements: Efficiency measures, Decision Cycles, Effectiveness measures, Communications, Decision quality, Process quality, Innovation,

Level of understanding, Implementation, Consensus, Social relationships, Influence, Confidence, General satisfaction, Attitudes (pre/post), Usability measures.

If somebody really describes a Delphi study in all the dimensions mentioned in the "factor model", they will have a lot of work to do. I like to call the "factor model" as a "Ptolemaic expert communication theory". Like the Ptolemaic cosmology, it seems to describe the communication processes perhaps rightly but in a very complicated way. It does not fulfil a benchmark of a good theory. Good theory has to be as simple and "elegant" as possible.

I do not assert that I know a "Keplerian expert communication theory". However, I consider that we will not find an elegant "Keplerian theory", if we only look for new simple empirical results. Instead of "Lockean empirism" we need a rationalistic structuration of the communication processes. Empirical evidence is reasonable only as a test of a structured model or theory. I hope that my epistemic utility model and three types of reasonability are steps forward in this type of rationalistic structuration.

In a Delphi process the production of epistemic utility is based on a special kind of group communication. Social psychological experiments have uncovered some basic general features of group communication which are relevant for the evaluation of the validity of judgements resulting from group communication processes. Before this discussion it is, however, useful generally discuss about errors that might produce invalid judgements concerning the future.

## 4.2 Sampling, Nonresponse and Response Errors

A basic idea of the GTC and my epistemic utility model is that an actor realizes her "good enough" plan (e.g. a technology generalization option) if the actor does not have to change her relevant criteria of sameness. This means that the realization of the plan belongs to her perceived capability and real capacity limits. The judgements based on this kind of plan might result in stabile or reliable transient invariances.

If it is reasonable to assume that

- the learning of the actor does not change the relevant perceived capability limits, which means that the plan also belongs to the perceived capacity limits (the plan remains invariant during the realization process);
- the realization of the perceived plan belongs to the real capacity limits of the actor or in other words: the actors have enough resources to realize his or her plan; and
- the actor tells her true plan;

then the told plan gives the valid prediction about a topic or about a technology generalization, if the realization of the topic or the technology generalization belongs to the plan.

Many market studies have been based on the above kinds of assumptions resulting in good predictions. The predictive reasonability based on opinion polls of consumers have been based on avoidance of three types of errors (compare Armstrong 1985, 82):

- *sampling errors* create problems in generalizing from the sample to the population of all relevant consumers having the needed resources;
- *nonresponse errors* create problems in generalizing from the respondents to the sample;
- *response errors* create problems in generalizing from the response of an individual respondent to his or her future behavior.

Market studies take often into account the first two errors but do not carefully take into account the third error. An example given by Armstrong (1985,82) illustrates the errors. Assume that you must forecast the sales of automobiles in the United States. A sample is selected from that part of the US. population which has enough to buy a car. The members of the sample are asked whether they expect to purchase a car within the next six months. Sampling errors result if the sample is too small or if it was selected from a list that was not representative of the population of potential automobile buyers. Nonresponse errors occur if individuals in the sample cannot be located or if they refuse to answer.

If the sample is large enough, it is often supposed that response errors of respondents eliminate each others. E.g. somebody answers that he will buy a car and in reality will not buy. This error is eliminated by another respondent who answers that she will not buy a car, but in reality will buy. If the potential buyers of cars have no systematic reasons to give misleading information, the disregard of the response errors is a reasonable choice. There are often, however, systematic response errors in market studies. A typical systematic error is e.g. that respondents want to answer in a way that makes them look good.

Two first types of errors are also relevant for technology Delphi studies in addition to marketing studies. In the case of car buyers it is relatively easy to identify the population of relevant consumers or decision-makers. But what is the population of experts being able to realize a technology generalization? We have two basic problems in this identification task. Firstly we often do not know who is capable to realize a generalization described by a topic. Even actors, who in reality will realize a technology generalization, are often incapable to anticipate their future success. This concerns especially topics having the form "when a generalization X will realize for the first time". Secondly experts cannot typically alone realize a topic. Often an extensive coalition of actors is needed. In fact the rele-

vant population in foresight studies is - unlike in market studies - not based on the capacity of respondents to realize asked topics. Panellists in technology Delphi studies are typically selected based on their expertise in relevant arguments<sup>2</sup>, not so much based on their capacity to realize some topics.

Unlike potential car buyers the panellists in a technology Delphi study typically have made no plans concerning the realization of a topic. Typically panellists present different scenarios based on arguments. Few experts having relevant plans are usually not very eager to tell about their plans because they do not like inform their competitors. This sometimes results in a nonresponse error. The more likely error is, however, the response error. Let us assume that an expert has a plan but he or she is not ready to inform other panellists. In the author's studies (Kuusi 1991 and 1994) he or she often made some kind of response error but did not refuse to be a panellist.

This and later chapters of this study are much focused on response errors of different kinds of panellists. An important conclusion of my study is that response errors of experts are interrelated. When a first best expert makes a response error it often results in bandwagon response errors of second or third best experts. The anonymity of Delphi studies can be an efficient way to avoid the bandwagon response errors, but not always.

In the beginning of this chapter I mentioned two forces, which have an impact on a Delphi panellist's evaluation: M or the possibly "expertise weighted" median or average answer of the panellists; and T or the "truthlike" or directly validated value which seems to be reasonable based on the arguments known by a panellist before the study and based on the information content of presented arguments of other panellists. My discussion concerning response errors in technology Delphi studies is very much focused on these forces.

In traditional opinion polls respondents are assumed to give their opinions independently, but in Delphi studies opinions of other experts or M has an impact. Though a Delphi panellist does not know whose responses result in M, it is for him or her a kind of representative of "public opinion" concerning a topic. As Timur Kuran (1995) extensively discusses in his book "Private Truths, Public Lies", people are inclined to give publicly opinions, which are somewhere between ones true (private) opinion and the public opinion.

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<sup>2</sup> For example in the UK study only 5% panellists classified themselves "belonging to that community of people who currently dedicate themselves to the topic matter" (the expertise level 5) but 46% considered that they "know most of the arguments advanced for and against some of the issues surrounding it, and had read about it, and have formed some opinion about it" (at least the expertise level 3) (Loveridge et al. 1995, 10-11, 22).

Let us suppose that an expert changes his judgement on the second Delphi round based only on the value  $M$ . Let us suppose that the panellist approves now the median value of the first round. When does this decision increase the invalidity of the median value? We can image at least one extreme case, when this is the case. Let us suppose that half of the panellists make the same systematic response error in order to mislead other experts. If some other panellist accepts their opinion he makes the same error.

You might consider that the risk of bandwagon error is, however, not very great if an expert sees that the judgement of other experts is false based on his past knowledge. Actually social dynamics may produce very strange results in this type of situation as some basic empirical results of social psychology which will be discussed in the next paragraphs indicate.

### **4.3 Some Relevant Social Psychological Discoveries concerning Group Communication**

A key prerequisite for any relevant theory concerning the validity of the expert judgements produced using the Delphi method is the profound understanding of the forces in human communication. Although group communication happens between learning actors, it is reasonable to assume that group communication could have at least some weakly invariant features. I agree with Rowe et al. (1991, 249) in their statement that in improving the Delphi method, "first priority should be given over to more intense analysis of the mechanics of change in nominal (not interacting) and interacting groups, which should subsequently allow us to develop stronger theoretical frameworks on which to construct techniques for improving judgement and forecasting."

I think that in order to find really relevant invariances we first have to discuss group communication on a very general level. The general understanding of social influence in groups helps us to understand the specific problems of the Delphi method.

Social influence in groups has been a well-studied topic in social psychology. Social influence on the general level refers to a change in the judgements, opinions and attitudes of an individual as a result of being exposed to the judgements, opinions and attitudes of other individuals (de Montmollin 1977, Avermaet 1995, 350).

A question of social influence vital for the Delphi method concerns conformity or majority influence. Do individuals change their opinions when they learn that the majority of the members of a group to which they belong holds a different opinion? Do they perhaps only give in overtly and maintain their own conviction in

private (e.g. their own vision of the generalization possibilities of a technology), or does the majority influence really change people's minds? Under which conditions do individuals manage to resist majority influence?

The next relevant general problem concerns minority influence. Can a minority in a group bring about changes in the opinions of a majority? What characteristics should a minority have in order to produce an effect?

Social influence has implications concerning group performance in comparison with the performance of individual members. The problem discussed by social psychologists in this context is highly relevant to our problems: how interpersonal processes may affect actual performance and could they keep a group below its potential performance?

A "paradigmatic" experiment concerning the group influence was made by Muzafer Sherif (1935, Avermaet 1995, 351). He placed subjects alone or in groups of two or three in a completely darkened room. At a distance of about 5 meters, a single and small stationary light was presented to them. In the absence of reference points, a stationary light appears to move rather erratically in all directions (autokinetic effect). Sherif asked his subjects to give an oral estimate of the extent of movement of the light, obviously without informing them of the autokinetic effect. Half of the subjects made their first 100 hundred judgements alone. On three subsequent days they went through three more sets of trials, but this time in groups of two or three. For the other half of the subjects, the procedure was reversed. They underwent the three group sessions first and ended with a session alone.

Subjects who first made their judgements alone developed rather quickly a standard estimate (a personal norm) around which their judgements fluctuated. This personal norm was stable, but it varied highly between individuals. In the group phases of the experiment, which brought together people with different personal norms, subjects' judgements converged towards a more or less common position - a group norm. With the reverse procedure this group norm developed in the first session and it persisted in the later session alone.

Sheriff's famous experiment did not strictly speaking concern conformity or majority influence. To turn it into conformity study, Jacob and Campbell (1961) firstly replaced all the subjects but one by confederates who unanimously agreed with a particular judgement. After every 30 judgements, a confederate was replaced by a naive subject until the whole group was made up of naive subjects. Their results indicated that the majority had a significant effect on the subjects' judgements even after they had gradually been removed from the situation (Avermaet 1995, 352).

A special feature in the experiments above was that there was no right answers to the evaluation tasks. The situation was different in experiments conducted by Salomon Asch (Asch 1951, 1956, Avermaet 1995 p. 352-354). In the experimental condition the subjects, who were seated in a semicircle, were requested to give their judgements aloud, in the order in which they were seated, from position 1 to position 7. Actually there was only one real subject, seated in position 6. All the others were confederates of the experimenter and, on each trial, they unanimously gave a predetermined answer. The answers concerned decisions, about which of the three comparison lines was equal in length to a standard line. On each trial one comparison line was in effect equal in length to a standard line, but the other two were different. All in all, the task was apparently very easy, as was shown by the fact that in a control group of 37 subjects who made their judgements in isolation, 35 people did not make a single error.

In six "neutral" trials (the first two trials, and four other trials distributed over the remaining set) the confederates nominate the correct lines, which were equal in length to the standard lines. In the other 12 "critical" trials they unanimously agreed on an incorrect line. The results reveal the tremendous impact of an "obviously" incorrect but unanimous majority on the judgements of a lone subject. Out of Asch's 123 subjects only about 25% did not make a single error compared with 95% in the control condition.

Essentially, similar results have been obtained on numerous occasions, using different subject populations and different judgmental tasks. The Asch effect reflects not only a conformist attitude or a specific culture as most replications have shown (Doms and Van Avermat 1982, Vlaander and Van Rooijen 1985, Perrin and Spencer 1980 for a negative finding).

Asch's experiment has provided the groundwork for a rich tradition of theoretical speculations and empirical studies in social psychology with potential relevance to Delphi studies:

- 1) The subject's perceived competence at the judgement task relative to others, as well as his self-confidence, reduces the amount of conformity (Mausner 1954).
- 2) Dittes and Kelley (1956) observed more conformity in subjects of medium status than in high-status or low-status subjects.
- 3) Di Vesta (1959) showed that more conformity was obtained on later trials if the early trials contained many neutral trials.
- 4) Asch (1951) ran groups in which the size of the "majority" varied from one to 16. One person had no effect, but two persons already produced 13 per cent errors. With three confederates, the conformity effect reached its full strength with 33 per cent errors. The addition of even more confederates did not lead to further increments in conformity.



- 5) Endler (1965) has shown that a direct reward for conforming responses leads to an increment in conformity.
- 6) Subjects who were informed that groups would be compared, conformed more than subjects for whom accuracy of individual judgement was emphasized (Thibaut and Strickland 1956).
- 7) Wilder (1977) showed that two independent groups of two people have more effect than four people who present their judgements as a group.
- 8) If one discovers that others hold opinions more in the direction of the valued alternative, one will become more extreme in order to differentiate positively from others (Lamm and Myers 1978, Avermaet 1995 368-372).

The process discussed by Lamm and Myers (1978) can in special conditions lead to an extreme form of "groupthink". There the decision process of a highly cohesive group of similarly minded people becomes so overwhelmed by consensus seeking and "positive thinking" that their apprehension of reality is undermined. Janis and Mann (1977) have described a number of instances of political and military decision-making which provide dramatic illustrations of the utmost stupidity shown by groups in spite of the superior "intelligence" of their members (e.g. The Bay of Pigs invasion in 1961).

An important question for the Delphi studies concerns the impact of minorities. When Asch gave the subject a supporter in the form of a confederate who answered before the subject and who gave correct answers on all trials, the conformity of the real subject dropped dramatically to a mere 5.5 percent from 33 percent (Avermaet 1995 p.356). In trying to find out whether the reduced conformity was caused by a break in the unanimity of the majority or by the fact that the subject now had a social supporter for his own private opinion, Asch added a condition, in which the confederate deviated from the majority but gave an even more incorrect answer than they did. The results showed that the extreme dissenter was nearly as efficient in reducing conformity as was the social supporter.

Allen and Levine (1968,1969) later showed that the conclusion only holds with respect to unambiguous situations as in Asch's experiments. With opinion statements only a genuine social supporter will lead to reduced conformity.

The perceived expertise of the supporter had an important impact. In an "Asch experiment" by Allen and Levine (1971) a supporter was given to the subject, but in one of their two support conditions the social support was invalid. The "invalid" supporter, although giving correct answers, could possibly not be perceived as a valid source of information because the subject knew that he had extremely poor vision (as was evident from a pre-experimental eye examination and from his eyeglasses with thick lenses). The results showed that although invalid social support is sufficient to reduce conformity significantly compared with an unanimous majority condition, the valid social supporter has much more impact.

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Some further observations have complemented the above results:

- 1) Consistent minorities are strongly disliked (Moscovici and Lage 1976).
- 2) A consistent minority, which behaves in a very rigid, extreme or dogmatic manner, is less influential than an equally consistent minority whose negotiation style is more flexible (Mugny, 1982).
- 3) If the minority appears to have something to gain from the position it takes, self-interest becomes a plausible alternative cause of their behaviour (Maass, Clark and Haberkorn 1982).
- 4) There is probably a privileged relationship between minorities and private change of mind on the one hand and majority and public change of mind on the other hand. Under conditions where minorities usually have to try to exert influence, they can at first expect just private change and only later public change (Moscovici and Personnaz 1980, Avermaet 1995 p.365-366).

The key role of consistency has been demonstrated in many experiments. In what is essentially a reversed Asch experiment, Moscovici, Lage and Naffrechoux (1969) had subjects participate in a study on colour perception in groups of six. Subjects first underwent a test for colour blindness. Upon passing this test they were then shown 36 slides, all clearly blue and differing only in intensity. Their task was simply to judge the colour of the slides by naming aloud a simple colour. Two of the subjects, seated in the first and second position or in the first and

fourth position, were actually confederates of the experimenter. In the consistent condition they answered "green" on all trials and in the inconsistent condition they answered "green" 24 times and "blue" 12 times. The experiment also contained a control condition, for which the groups were made up of six naive subjects.

Out of 22 naive subjects, only one person gave two green responses in the control condition. In the inconsistent minority condition, the number of green responses was only slightly and insignificantly higher than in the control condition. In the consistent minority condition, 32% of naive subjects gave at least one green response. There were two categories of groups: those in which nobody was influenced, and those in which several people were influenced. A typical observation was that, in contrast to conformity studies, the minority effect only begins to show after a certain period (Nemeth, 1982).

Why the social influence is so important in human learning? Kuran (1995, 162-167) gives an explanation. He considers that free riding on the knowledge of others is an essential vehicle for overcoming one's cognitive limitations. If others have investigated an issue in depth and their judgment can be trusted, one can dispense with the trouble of reflection by appropriating their apparent understandings. Kuran considers that we often rely the *heuristic of social proof* (Cialdini 1984): if a great many people think in a particular way, they must know something we ourselves do not. Even where we possess independent knowledge, the fact that our perceptions are shared assures us of their correctness. It is a reasonable search routine for learning (compare Loikkanen, 1996).

Even in scholarship, where the authentication of ideas is supposed to be based solely on logic and evidence, appeals to social proof are common. Academic writers routinely cite great scholars to bolster the credibility of their assumptions and inferences. Scientific or technological paradigms are partly adopted based on social proofs. Scholars draw support from the presumed agreements within their disciplines. Many academic writings are peppered with phrases like "the standard assumption" and "as is well known" (Kuran 1995, 165).

It seems not be far from the truth to consider, that the traditional Delphi method has in practice been based just on social proofs of experts, though in principle also factual arguments are distributed during traditional Delphi processes. Though the anonymity of experts helps to avoid at least partly the "fallacy of argumentum ad hominem"<sup>3</sup>, the "fallacy of argument ad nauseam" is difficult to

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<sup>3</sup> Kuran (1995, 168-169) gives a nice example of this fallacy. A visitor arrives in front of a Cubist painting signed "Picasso". "Phenomenal!" he exclaims, "it's creative, and the colours are subtle". Suppose we had replaced the signature on the painting "R. Barney" and placed it among works by unknown local artists. Our visitor might well have dismissed the otherwise identical painting as unimaginative.

avoid in traditional Delphi studies. According to this fallacy many falsehoods have attained the status of truth through reiteration. Multiple exposures to a single belief produce a social proof. If in a Delphi panel is a majority of like-minded experts, which do not represent the general opinion of all experts, they produce a social proof of their opinion.

Even the presentation of a topic is a kind of social proof. In an experiment cited by Kuran (1995,166) a group of subjects were exposed to sixty plausible statements, each either true or false (Hasher et al. 1977). Here are two examples: "In the U.S., divorced people outnumber those who are widowed" (which at the time of the experiment was false), and "In Malaya, if a man goes to jail for being drunk, his wife goes too" (which was true). After hearing the statements, the subjects were asked to rate the validity of each on a seven point scale. Two weeks later, and again two weeks after that, the subjects were exposed to additional sets of sixty statements, each of which included twenty from the original list. As with the first session, the subjects were asked to rate each statement for its validity. A comparison of the ratings from the three sessions shows that the subjects treated exposure as a criterion of validity. For the repeated statements, whether actually true or false, the mean rating was significantly higher in the second and third sessions than in the first.

#### **4.4 Does the Delphi Process Produce More Valid Judgements than Staticized or Nominal Groups: Empirical Results concerning the Predictive Reasonability**

The discussed invariances of group communication are helpful in analysing the results of some empirical studies which have tried directly to evaluate how information about the "expertise weighted median or average opinion" (M) may produce valid argumentation. A basic weakness in laboratory experiments, which have tried to evaluate the validity of the Delphi method directly, has been that they have focused on predictive reasonability. Actually, I have found no laboratory experiment which tried to evaluate the option reasonability or commitment reasonability of the Delphi method. Hence the "valid judgement" in cited in the studies below usually means the "predictive valid judgement".

In many studies, the Delphi method or *structured indirect interaction* has been compared with an average of responses from the poll of experts ("*staticized group*", individuals working alone) or with results of *unstructured, direct interaction* in a group ("working group, committee"). The fourth possibility has been *structured interaction with phases of direct interaction*. Nominal group technique is perhaps the most widely known structured, direct interaction method (Woudenberg 1991, 132). Like many similar methods (e.g. the "futures work-

shop" method often used in Finland), it includes phases of direct interaction and phases where panellists give evaluations anonymously or semi-anonymously.

The experiments seem to focus on the following hypotheses:

*Hypothesis 1: The average judgement of a communicating expert group is more valid than the average judgement of separately evaluating experts ("staticized group").*

*Hypothesis 2: The Delphi method or structured indirect interaction produces more valid judgements than the unstructured or direct interaction of experts ("working group" or "nominal group").*

*Hypothesis 3: The experts high in self-evaluated or peer-evaluated expertise produce more valid judgements than experts who have received low evaluations.*

The discussion concerning *the first hypothesis* began already in the 1930s. Douglas MacGrecor undertook a study in 1936 and formulated what came to be known as the "MacGrecor effect". This refers to his finding that predictions made by a group of people are more likely to be right than predictions made by the same individuals working alone (Loye 1978 ref. Lang 1996).

The simple idea, that a group makes better predictions than its single members, is very questionable, as many comparison studies of performances of staticized groups and interacting groups have indicated. Individual and group task performances have often been tested by problems with known answers. A typical experiment was made by Jenness (1932, ref. Metcalfe 1995, 67-68). He asked subjects to estimate the number of beans in a jar. Participation led to consensus but did not improve accuracy. Dalkey (1967) found that individuals outperformed groups on almanac questions with known answers like "what was the true value of the Finnish mark against the US. dollar in January 1990".

The results of many studies contradict the "MacGrecor effect". For example Kaplan et al. (1950, ref. Metcalfe 1995, 68) asked 26 subjects to make over 3000 separate forecasts based on 16 events in the social and natural sciences. They found that participation in a group of four followed by individual forecasts resulted in 62% correct forecasts. Individuals working alone were correct in 63% of the cases.

What kind of evidence has been presented concerning *the second hypothesis*? A comparison study of traditional Delphi and an unstructured, direct interaction process was made by Klaus Brockhoff et al. (Brockhoff 1975, 291-321). The study tried to test directly a group of hypotheses thought to be crucial to the va-

lidity of the Delphi method. Their starting point was the traditional Delphi method with some exemptions mentioned in the parentheses.

The participants in the group were not supposed to establish immediate contact with each other. They responded to all questions in writing. The responses were divided into three classes: (1) responses that were known only to the experimenters; (2) responses which, after the responses of all participants had been received by the experimenter, became objects of computing procedures, the results of which were made known to all participants; (3) responses which were recorded and made known to all participants without any changes.

Concerning the Delphi groups, the first class included the name of the participant and the degree of expertise that he expressed with regard to each question. The questions concerned banking and both the Delphi panellists and the members of "normal" control groups belong to the permanent staffs of the local banks. To the second category belonged the quartile and median values of individual responses to forecasting questions. The third category included all arguments for divergent opinions of those whose responses lay outside of the lower (0.25) or upper quartiles (0.75). The rounds of the Delphi study meant that Delphi panellists were able to change their minds based on the information (medians, quartiles and arguments of divergent experts) obtained from the previous rounds.

Beside Delphi groups Brockhoff et al. had face-to-face or normal groups of 4-10 persons. In these groups, the group members were asked to introduce themselves to each other by name, field of employment, official position and number of years spent in banking. The idea was, as is normal in working groups, to provide each participant with a basis for judging the experience of the discussion partners in the subsequent discussions. Furthermore, the participants were asked to specify their degree of expertise for each question on a record. They noted their personal estimates for each question before any discussion took place. A discussion of the problem was expected to follow and unanimous group estimate was required (Brockhoff 1975, 305).

Two types of questions were asked: fact finding questions and forecasting questions. Both questions referred to finance and banking items which were reported for example in the monthly statistics of the German Federal Bank. In all cases, the correct responses could be verified objectively at the time of the experiments or of a later date.

In these conditions, Brockhoff et al. tested the following hypotheses:

- 1) With increasing group size, the group performance increases *ceteris paribus*.

- 2) With increasing self-evaluated expertise, group performance increases *ceteris paribus*.
- 3) The performance of Delphi groups is *ceteris paribus* higher than the performance of natural groups.
- 4) The performance of the Delphi groups increases *ceteris paribus* with increasing number of rounds at least at first.
- 5) The variance of answers around the median decreases *ceteris paribus* with increasing number of rounds.
- 6) The performance of a group in answering fact-finding questions is *ceteris paribus* equal to that in forecasting.

A clearly statistically confirmatory result was obtained only for the fifth hypothesis, as in most similar laboratory studies, though a reduction of the variance of responses also happened in normal groups: the Delphi process evidently produced consensus, but not better performance compared with the normal group.

Brockhoff et al. (1975, 320) made the following generally interesting final conclusions:

- 1) It cannot be discerned that fact-finding questions are a suitable test material for recognizing expertise or appropriate organizational structures for forecasting groups (different panellists were good in fact finding and forecasting)
- 2) A general positive relationship between group size and group performance cannot be recognized.
- 3) In face-to-face discussion groups, the measure of the group size must be determined by the number of active participants.
- 4) Variance reduction almost always occurs in Delphi groups between the first and fifth rounds, but the best results are as a rule already known in the third round. Further rounds may impair results.
- 5) Self-ratings of expertise show a positive relationship to the performance of the persons questioned in only two of the four Delphi groups. They tend to be lower in face-to-face discussion groups than in Delphi groups, and are determined substantially by the extent of professional experience rather than being set with regard to the questions in case. It is important to employ and develop better methods for the determination of expertise.

6) Only in the Delphi group with the greatest exchange of information did researchers observe a positive relationship to group performance. The results indicate that in small Delphi groups more opportunities for information exchange should be given.

Woudenberg (1991) has made a summary of the studies - including the study of Brockhoff discussed above - relevant for the first and the second hypotheses. In these studies the accuracy of the Delphi was compared with a staticized group; unstructured, direct interaction; and structured direct interaction. The summary is presented in table 4.1. In most studies no statistical comparison between methods was made. According to Woudenberg, a slight - but not unequivocal - indication for Delphi's expected higher accuracy as compared with unstructured, direct interaction can be observed. A similarly unequivocal suggestion can be made in Delphi's lower accuracy as compared with the staticized group. The comparison between Delphi and structured, direct interaction suggests that there is no difference in accuracy. The conclusion made by Woudenberg (1991) was that the comparisons between Delphi and all other methods show no difference.

*Table 4.1 Pairwise Comparisons of the Accuracy of Judgment Methods*

		Delphi		
		More accurate	Equally accurate	Less accurate
Staticized group	vs Delphi	2	1	5
Unstructured, direct interaction	vs Delphi	5	3	2
Structured, direct interaction	vs Delphi	2	4	2
All methods	vs Delphi	9	8	9

The summary of Woudenberg is as questionable as the summary of Armstrong (1985) discussed in the paragraph 4.1. The comparison of studies does not produce very informative results without taking into account the differences of situations in the studies.

Zajonc (1965, ref. Hewstone et al. 1995) has presented perhaps the most important situational factor relevant for the accuracy of judgments of staticized groups and of groups with social interaction. The basic suggestion of Zajonc was that the presence of others led to improved performance (social facilitation) if subjects worked on easy, well-learned tasks. However, the presence of others led to impaired performance (social inhibition) if subjects were engaged in difficult tasks which were not (yet) well learned.

Zajonc's theoretical explanation was that audiences enhance the emission of dominant responses. A dominant response is described as the response which



prevails, that is which takes precedence in a subject's response repertoire in a given stimulus situation. In easy tasks, Zajonc argues, that the correct responses are dominant and therefore audiences facilitate performance of easy tasks, e.g. pedalling a bicycle. However, in complex tasks the wrong answers tend to be dominant, and therefore audiences give rise to performance deterioration on such difficult tasks.

The results of a Delphi study by Dalkey (1969, Woudenberg 1991, 136 ) can be explained by the argument of Zajonc. Dalkey asked students to answer simple almanac-type questions such as "In what year was nylon invented". In this study, the answers mostly improved as a result of Delphi process. On the other hand, the questions in the study of Brockhoff et al. (1975) were rather difficult. The dominant responses were probably not better than the answers of single panellists.

One of the Brockhoff's conclusions concerned *the third hypothesis*. The hypothesis obtained only weak or no support from the study. It seems that second best experts are often better evaluators than the first best experts because the first best experts are often inclined to make response errors, as will be discussed more closely in Chapter 5.

The perceived expertise and the social proofs are closely related. Henchy and Glass (1968, ref. Hewstone et al. 1995) made an experiment which directly illustrates the role of perceived expertise in group decision making. They assigned subjects to one of four conditions: "alone", "expert together" (i.e. task performance in the presence of the others, explicitly introduced as experts); "non-expert together" (i.e. task performance in the presence of two non-experts) and "alone recorded" (in which the subject performed the task alone, but was filmed for later evaluation of experts). In this experiment conformity responses only occurred in the experts-together and alone-recorded conditions, while task performance in the non-expert-together condition was similar to that in the alone condition. The study clearly supports the conclusion, that for the validity of the judgement the distorted judgement of a perceived expert is especially damaging. In a version of the Asch experiment more conformity was obtained if the group firstly gave right answers (Di Vesta 1959).

#### **4.5 Evaluation of the Empirical Results from the Point of View of Option and Commitment Reasonability**

We have seen in the previous chapter that the real focus of the recent national technology Delphi studies is more on option reasonability or the commitment reasonability than on prediction reasonability. The studies are not seeking what will actually happen but what will reasonably happen from the point of view of a single actor or from the point of view of a group of committed actors. *Recent*

*foresight studies help actors to make choices concerning futures.* A common feature of the empirical studies discussed above was that future developments or other evaluations on which the study subjects had no impact or a minor impact were asked. The subjects looked at topics as outsiders.

In the previous paragraph I evaluated Woudenberg's summarizing study concerning the prediction accuracy of the Delphi method in comparison with other methods. Woudenberg's results obtain new interpretations, if we remove the implicit "outsider assumption" of the discussed studies. Woudenberg's result, that statizised groups make more accurate judgments than Delphi groups, is reasonable in short run predictions based on existing plans of actors like the plans concerning the buying of cars. If somebody has a ready plan to buy a commodity, it is reasonable to assume that the information got from him or her is more valid, if she or he does not take into account the impression which he or she gives to other people. If she or he takes into account the impression, he or she is inclined to answer in a way that makes her or him to look good. If the asked product is socially approved, respondents might overestimate their purchases and vice versa.

If the social commitment is, however, very clear and public, a person is not capable to behave unlike he publicly expresses. Amstrong (1985, 83) has cited a simple study where the correlation between intentions to donate to a church and actual donations was .92. In this case the church asked members to sign pledges.

As was discussed in the chapter 3, option reasonability or commitment reasonability of an option does not implicate its predictive reasonability. It is also so that all prediction reasonable (or rightly predicted) events are not option or commitment reasonable. It is possible that a realized event (or a realized technology generalization) is actually reasonable from nobody's point of view.

I consider that a main function of recent technology foresight studies has been to increase the prediction reasonability of commitment reasonable technology generalizations or at least option reasonable technology generalizations. This aim means that relevant actors have not to regret those technology generalizations, which will be realized. The discrepancy between the prediction reasonability and the option/commitment reasonability has many causes. A basic cause for the discrepancy between the prediction reasonability and the option reasonability is that actors do not know different options or do not have enough valid information concerning impacts, feasibility and relevancy aspects of technology generalization alternatives. A special problem related to the discrepancy between the prediction reasonability and the commitment reasonability is that an actor is not able or does not like to tell his or her real future plan. This is connected with the problem of tacit or hidden knowledge which I discussed in the previous chapter. If experts do not know each others plans, they cannot build a co-ordinated plan, which is more commitment reasonable choice.

How should the hypotheses discussed in the previous paragraph be formulated from the point of view of the option/commitment reasonability? Let us assume that an evaluated future event is a possible technology generalization  $b$ . The option reasonability and the commitment reasonability require that for at least one actor  $k$  the total value of  $I_b - F_b - V_b - R_{bk} - L_k$  is reasonably higher than zero (the generalization belongs to the real capability limits of  $k$ ). Based on the definition given in the chapter 3, this means that if  $k$  does  $b$ , she or he will not repent or regret it. In practice, it is of coarse beforehand impossible to decide, which options will not be repented. One can only present arguments related to repentance, as one can present arguments concerning true predictions. From the points of view of the option reasonability and the commitment reasonability it is possible to formulate the three hypotheses in the following way :

*Hypothesis 1 A communicating expert group can make more valid evaluations than separately evaluating experts ("staticized group") concerning an actor (or actors)  $k$  who can realize  $b$  and will not repent the realization, if the actor(s) does it .*

*Hypothesis 2 The Delphi method or structured indirect interaction produces more valid judgements than the unstructured or direct interaction of experts concerning an actor (or actors)  $k$  who can realize  $b$  and will not repent the realization, if the actor(s) does it .*

*Hypothesis 3 The experts high in self-evaluated or peer-evaluated expertise produce more valid judgements than experts who have received low evaluations concerning an actor (or actors)  $k$  who can realize  $b$  and will not repent the realization, if the actor(s) does it .*

Even after  $k$  has accomplished  $b$  it is very difficult to detect, should he or she reasonably repent. What we are able to know are arguments concerning the components of a reasonable choice: arguments concerning impacts, feasibility, validity and relevancy of  $b$ . New relevant arguments might change the mind of an actor. If we know arguments which the actor does not know, we might reasonably suppose that the actor might repent the realization of  $b$ .

The results concerning prediction reasonability are not without qualifications useful for a study focused on option reasonability or commitment reasonability. They bring to the discussion a new aspect which is not very relevant for prediction reasonability. This is the *information policy* aspect.

If a group of outsiders predict realization of technology generalization  $b$ , they are typically ready to give their best information to the other members of the expert panel. The situation is altogether different if panellists are involved in the realization of  $b$ .

I give the following definition for "competent experts" concerning a technology generalization b: competent experts of a technology generalization b are informed about most factual arguments relevant for the realization of b and have before the argumentation process an opinion concerning the realization of b. This was the criterion which was used in the United Kingdom foresight study for dividing Delphi panellists in "experts" and other panellists. Literally the criterion was that experts were familiar with the topic "knowing most of the arguments advanced for and against some of the issues surrounding it, and had read about it, and have formed some opinion about it" (Loveridge et al. 1995, 10)<sup>4</sup>.

Competent experts are seldom outsiders in the realization of b, though only about one tenth of competent experts considered that they are closely involved in the realization of a topic based on the UK Technology Delphi survey. In that study one-tenth of competent experts classified themselves "belonging to that community of people who currently dedicate themselves to the topic matter" (the level 5 of expertise, Loveridge et al. 1995, 10-11, 22).

Information policies of involved experts are often based on a complex interaction process or game among different types of experts or stakeholders. A competent expert often likes to hide his or her knowledge because anticipated "*negative commitment effect*". Some experts or their organizations might have already started the realization of b but do not report it to other panellists if they do not want others to commit themselves to the realization. The actor does not like that another decision maker (e.g. a competitor) uses his or her knowledge (e.g. without compensation) in the decision making.

There are special cases in which avoidance of a negative commitment effect is a very reasonable choice. Let us suppose that to the expert group belongs an actor k, who is a key person in the realization of b. There might be such a technology generalization option c that it is not reasonable for k to realize both b and c, e.g. based on resource limitations. It is, however, possible that the realization of both b and c belong to the real capability limits of k: if k realizes only b or only c,

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<sup>4</sup> In the last Japanese study panellists evaluated their expertise with a scale (NISTEP 1997,6):

*High*: Has considerable specialist knowledge about the topic through current research or work related to the topic (including research based on literature);

*Medium*: Was once engaged in research or work related to the topic; or has some specialist knowledge about the topic in an adjoining field;

*Low*: Has read technical books or literature about the topic or has listened to experts connected with the topic; and

*None*: Has no expertise.

The scale in the German study (Cuhls et al. 1998) gross-mittel-gering-fachfremd was similar to Japanese study. "Gross" was, however, perhaps closer to the "high involvement" 5. level of the UK study because of a remark: "Dies (gleichen Thema, entsprechenden Themen, the author's addition) sind Ihre eigenen Arbeitsgebiete!". In reality it is very difficult to control in surveys how the respondents have interpreted the scales. In an interview it is easier.

she/he will not regret. From the point of view of another competent expert there might, however, be a great difference between b and c. In this situation it is reasonable for the competent expert (let say m) not to tell all the relevant arguments, which he/she knows, if the new arguments might change the choice of the first key person k between b and c. In this case *the optimal information policy of the competent expert is not to tell his/ her best information.*

On the other hand, experts try also to produce *positive commitment effects*. If experts want others to commit themselves to some activity they are inclined to exaggerate its promises. Two empirical studies cited by Armstrong (1985, 88) illustrate the point. Ogburn found that students at colleges with losing football teams had forecast that their teams would lose by an average of 3 points. The actual defeats averaged 18 points. Hultgren examined quarterly forecasts of tons of freight shipped over railroads from 1927 to 1952. The forecasts were made by experts employed by railroad shippers. Forecast errors ranged from being too low by 1,7% to being too high by 40,5%.

*I think that a basic difficulty in national technology foresight studies is to handle the different information policies of experts and impacts of these policies on social psychological processes in groups of experts.*

Let us focus discussion of the above issue on real choices in national technology foresight studies. As we have seen in the previous chapter, the studies have included typically "nominal group stages" and "Delphi stages". In the UK foresight study (Loveridge et al. 1995), there was a nominal group Panel in every sector or in every field of expertise. The Austrian study even has a "staticized group" stage where 1000 consumers were asked about their attitudes concerning different technologies (Delphi Report Austria 1. 1998, 27). The typical nominal group stage in the national studies has been the production or the selection of topics for different fields of expertise. It has happened in groups of typically 10-25 members. Finland has even tried to do almost the whole foresight job in these types of groups (Tiellä... 1997). Most of the recent national studies have, however, clear Delphi stages. In these stages, rather large groups of experts (typically 100-300 persons) had anonymously evaluated any single topic. There has typically been only a minimal risk that an expert has been identified by some other experts because even the feedback arguments have been presented in a standard form ("proxy arguments").

The option reasonability (and hence the commitment reasonability) of the national technology foresight studies is based largely on the quality of evaluated topics. *The choice of topics is not a "harmless preliminary stage" in a technology foresight process.* I consider that it is at least in some connections the most important stage in the whole process. This has been realized especially well in the Austrian national Delphi study. Besides the use of the field-specific working

groups, a survey of 1000 consumers and another survey of 370 experts were made to specify the most interesting fields and topics for the Delphi stages. Unlike in the Delphi stages of the Austrian process the firm experts did not dominate in the surveys (Delphi Report Austria 1998 1, 46).

Let us look at a choice process of topics in a working group. Based on the social psychological findings discussed in the paragraph 4.3, the choice process might have following problems:

- Because rigid minorities are disliked (Moscovici and Lage 1976), dissidents in the working groups might prefer to co-operate with the majority and with high-status experts. Members of a working group, who do not accept the judgements or arguments of the high status experts, might easily give up the argumentation concerning topics.
- Low-status representatives might present arguments supporting the suggestions of high-status experts, because they like to be rewarded by the high-status experts (Endler 1965, Lamm and Myers 1978).
- If there are two or more comparatively equally represented points of views (or technological paradigms) in a working group, the result might be many "value parties" or relatively separate subgroups inside the working group. The result might be "group polarization" with more extreme and conflicting opinions between the subgroups than the original judgements of the experts (Myers 1982).

We have real problems with the validity and relevancy of the results if the above conclusions are valid concerning the nominal or Delphi groups of experts used in the national technology foresight studies and if the high-status (or best) experts are inclined to hide or to distort their best information.

Is it reasonable to suppose that the above social psychological results do not concern the experts of the national technology studies? Can we suppose that the experts are less sensitive to the group influences than the students typically used in the experiments? Some experiments have shown that social norms are more effective than personal properties of individuals. Pettigrew (1958, Avermaet 1995, 386) found that white South Africans showed very high levels of anti-black prejudice, as did respondents from the southern United States. In terms of personality type (e.g. in authoritarianism), they were rather similar to the "normal" population. Based on these types of results, it is essential to look at the norms of the groups or institutes to which the technology experts belong. The role of social norms was realized e.g. by the Delphi managers of the first German technology Delphi (Grupp 1993, 16):

Technische und wissenschaftliche Aktivitäten sind eingebettet und interagieren mit einer komplexen sozialen Struktur. Die dabei zu treffenden Entscheidungen, etwa über die Aufnahme neuer Arbeitsgebiete, sind nur begrenzt rational, weil sie von erheblichen Unsicherheiten und Karriereerwartungen abhängen.

The scientific institutions typically reward those who present new ideas, even if the ideas are only partly validated. We might suppose that representatives of scientific institutions do not readily accept majority opinions or the opinions of high-status experts because they are rewarded on the basis of early innovations and criticality. It is reasonable to suppose that they are comparatively immune to group influences. Because of the norms of their institutions, they are also more inclined to deliver their best information. They might, however, be inclined to build "value parties" to support their favorite ideas.

The group influences seem to be a bigger problem concerning representatives of institutes which appreciate co-ordinated action and loyalty more than originality. Many firms and government agencies have this kind of norms. The representatives of firms used also be most inclined to an information policy restricting the delivery of the best information.

Besides the quality of expert arguments, norms have impacts on the motivation of experts to participate in foresight exercises and on their eagerness to produce arguments. Ahti Salo (1999) has suggested that the need to consider incentives is greatest when the exercise lacks strong support by leading authorities and is not related to priority setting.

#### **4.6 How to Improve the Interaction Processes in Technology Delphi Studies?**

In this paragraph, I will discuss some possibilities to improve the technology foresight processes in order to avoid bad results based on information policies of experts and on the effects of group dynamics.

Anonymity, large groups of experts and standardized "proxy-arguments" have helped to avoid the combined problem of information policies and group dynamics in the Delphi stages of national technology foresight processes. Most of the national studies have also taken into account some weaknesses of classical Delphi studies realized e.g. by Brockhoff et al. (1975). The consensus of experts is no longer a special target of the studies. Most studies do not punish the dissident views with a special requirement for further argumentation.

Though clear progress has happened, especially in the Delphi stages of the foresight processes, I think that there are still many possibilities to improve the validity and relevancy of the results of the foresight studies. My basic suggestions are as follows:

- selection of working groups and Delphi panels that takes into account the information policies and group influences beside the experts' expertise in relevant arguments;
- reduction of status differences between the experts used;
- asking for the best unbiased information of experts and the deliberate use of protagonists and antagonists; and
- active roles of Delphi managers and synthesizers.

#### **4.6.1 Careful selection of experts based on their positions in the developer community**

The selection of experts for the national technology foresight studies has been based on a balance between representatives of three or four basic types of institutions: science institutions, firms, regulatory institutions and other e.g. consumer institutions. In the last two Japanese studies the share of both company employees and university related panellists have accounted for 38%, public servants for 15 % and others for 10% (NISTEP1997, 11). In the last German study, the target was to get one-third of the experts from industry and one-third from universities and other research institutes. One-third of experts in any field of expertise was planned to be public servants or representatives of associations (Cuhls et al. 1998, 7). In the Austrian study, the representatives of firms dominated. They accounted for 56%. The representatives of science accounted for 22 % as did public servants and representatives of associations (Delphi Report Austria 1, 1998, 72). Representatives of firms also dominated the UK panel. If we divide 26% of the panellists in the category "main activity not known" into other categories according to their sizes, we get the following percentages: experts working in firm-related activities 65%, academic research 24 % and others 11% (Loveridge et al 1995, 21).

The dominance of firm representatives in many national panels is a problematic feature, when we take into account the above considerations concerning the information policies of panellists and group influences. In the next chapter, I will discuss the norms and information policies of representatives of basic institutions, which are relevant in most technology foresight studies.



The institutions of developer communities of specific generic technologies are divided into

- basic research and education of generic technologies;
- generalization organizations based on specific generic technologies;
- rival generalization organizations based on different generic technologies;
- application organizations;
- regulative or financing organizations; and
- consumer stakeholders (e.g. political parties, consumer organizations, environmental organizations, trade unions).

The developer community is a community of experts and their institutions involved in the realization of similar technology generalizations. Though the typical norms and the information policies of basic institutions give a crude general picture of the rules of the game of the technology foresight activities of developer communities, any developer community has its peculiar features. These peculiar features have to be taken into account in the selection of panellists. It is not reasonable to assume that the structures of relevant developer communities is known before the identification of potential panellists and their real institutions. There are many information sources for the identification of potential experts as is e.g. discussed in the Delphi Report Austria 1 (1998, 70-71):

- Co-nomination analysis, in which experts in a field of issues nominate other experts based on some criteria of expertise. This can happen using questionnaires like those of the UK study (Loveridge et al. 1995) or using telephone contacts as in the last German study.
- Catalogues and Internet homepages of relevant institutions (e.g. research institutions, universities, associations)
- Lists and Internet home pages of innovative firms
- Catalogues of exhibitions. An example was Hawaii communication conference attendance used in the study discussed by Ono and Wedemayer (1994).
- Contributors in expert publications
- Field specific sources e.g. EMAS certified firms, prize winners.

It is also possible to do the first nominal group stage or the first Delphi stage in a way that makes it possible to add new experts based on feedback from panellists. This is also possible in a Delphi stage and not only in a nominal group stage if interviews are used in the first Delphi stage as in the Argument Delphi.

Though the study of Brockhoff et al. (1975) is clearly too small and too specific for general conclusions, it suggests two conclusions which seem to be important for the selection process of the experts used: a) the number of experts is not decisive for valid judgements but the rightly perceived expertise of experts is (compare Brockhoff's conclusions 1, 2 and 5 in the paragraph 4.4.); and b) the active communication of arguments is important and not the size of the group ex-

changing arguments if the average level of expertise is the same in the compared expert groups (Brockhoff's conclusions 3 and 6).

The last German study has stressed the number of panellists as the source of valid judgements. The report of the study states the following (Cuhls et al. 1998, 7): "Because nobody can know exactly what will happen in the future, as many people as possible should participate. It has been shown that it is possible to avoid individual mistakes based on a great number of answers and so to increase the probability of 'right predictions' ". I do not deny that large panels might have positive impacts on the quality of foresight activities. The most important positive impact might be that experts (and citizens) obtain an overview concerning future prospects of other experts. Beside positive commitment effects somebody might e.g. realize that others have not yet understood the importance of an emerging opportunity (compare my discussion concerning the PCR in the paragraph 6.3). The large panel might also have positive impacts on the validity of judgements based on changed information policies of experts. The anonymity is more secure in a large panel. On the other hand an expert can present false statements with less risk.

In a trivial but empirically important case the quality of expertise and not the number of experts is decisive: a panellist or her/ his organization has already realized a technology generalization with good results but the other experts are unaware of it. This has happened at least once in a national technology Delphi study of Japan. It can also happen in this type of case that the delivery of information concerning the innovation does not belong to the optimal information policy of the panellist. In one of the author's technology Delphi studies an expert asked me to mark the realization of an innovation to the year 2010 though the innovation was nearly ready in the laboratory of the panellist.

The analysis of a developer community for the selection of the experts has to take into account the personal perspective. Linstone et al. describe the role of the personal perspective as follows (Linstone et al. 1981, 296):

There are clearly many persons who interact, directly or indirectly, with a socio-technological system. There are beneficiaries and victims, builders and users, regulators and lobbyists. Then there are the "hidden movers". These are individuals who, from a second or third level position, pull the strings that determine, how things progress. Attention is usually so keenly focused on the behaviour of the puppets, which is overt, that the effect of the puppeteer, who is hidden from view, is ignored... Still, the "gatekeeper", the person who controls the information flow in an organization, is often difficult to identify.

In the selection of experts, technical, organizational and personal perspectives should be taken into account in a balanced way. An example discussed by Lin-

stone et al. (1981, 315-316) illustrates the point. Guayule is a rubber-producing plant suitable for growth in semidesert areas such as the South-western US. It is a substitute for natural rubber obtained from the hevea tree. A technology assessment project evaluated the future use guayale (let us call it the technology generalization option b) from different perspectives (Foster et al. 1980).

From *techno-economic perspective*, Guayule has been tested and found quite satisfactory as a replacement for hevea rubber. A world-wide shortfall of natural rubber was anticipated by 2000. The experts who know these types of facts can produce important information concerning the impacts (I), feasibility (F) and relevancy (R) of b.

From the *organizational perspective*, there was a network of researchers which has been keeping interest in guayule alive for decades. But this was not sufficient to get commercialization off the ground. A coalition with adequate leverage was needed. Since rubber is a strategic material in the event of a national crisis, both the Department of Defence and the Federal Emergency Management Agency could become the core of this coalition. The organizational perspective gives information concerning a coalition of experts for which the realization of b might be a commitment-reasonable choice. It is important that these experts are represented in the foresight activities.

From the *personal perspective*, there was a crucial difference between those who were emotionally tied to guayule and those who must make commercialization decisions. The personal perspective gives hints, e.g. concerning the information policies of experts. Linstone et al. (1981, 306) made an interesting methodological remark: interviews play dominant role in taking into account of organizational and personal perspectives. This was also realized in the applications of the Argument Delphi.

#### **4.6.2 Reduction of status differences between participating experts**

Besides the norms of institutions, the perceived status differences between experts seem to product bad group influences. In order to avoid perceived status differences I suggest a "plurality policy" in the appointment and motivation of experts. The expertise should not be seen as a one-dimensional phenomenon but as a multi-dimensional. The "plurality policy" implies that every participating expert is a "high-status" expert based on his/ her specific type of expertise.

A panellist can achieve his or her high status as a representative of an important stakeholder group of the developer community. Even if a panellist considers that she/ he is not a real expert concerning a technology generalization, she/ he is a high-status expert because the expert represents the stakeholder group. In order to

avoid bad status effects it is not reasonable to communicate the personal qualifications of the panellists, though the Delphi managers should select the most personally qualified experts to represent the stakeholder groups.

The epistemic utility model also provides a sound basis for the plurality policy. Different experts are often best experts in the impacts, feasibility and relevancy of technology generalizations. The best experts differ in arguments concerning genuine invariances, transient invariances, arguments concerning reasons for relevancy evaluations or arguments concerning capacity limits of relevant actors. Some persons in a developer community know the possible techniques, some the possible markets of the products and some are gate keepers of relevant monetary or other resources. The reactions of some stakeholders - who perhaps do not understand the techniques discussed - indicate the reactions of ordinary people.

#### **4.6.3 Asking for the best unbiased information of experts and the deliberate use of protagonists and antagonists**

I consider that the argumentation in technology foresight studies should be based on the following rule: use the best unbiased information available from an expert.

As we have discussed above, the delivery of information can have positive or negative commitment effects from the point of view of an expert. The positive or negative effects depend on the type of actors with whom the information is shared. Eerola (1996) has divided technology foresight studies in three basic types:

- 1) *private technology studies* serving primarily individual companies or organizations,
- 2) *joint studies* or *multi-client studies* serving wider business communities that share some common interests and
- 3) *public technology studies* intended to serve the entire society or some important parts of it.

Private technology studies that are carried out confidentially by companies' own experts and trustees (consultants, researchers, etc.), although external informants may still be widely invited to provide the inputs required. Respectively, joint studies mean technology studies that are carried out as joint projects by all those organizations sharing the costs of the process and the resulting messages on future technologies. Multi-client studies refer to technology studies that are carried out by consultants or research institutes that, in turn, sell the resulting study reports to those sharing the interest. The initiative for a multiclient study may also come from those buying the study. As for private studies, additional informants

can be integrated to provide inputs for joint studies and multi-client studies when needed.

Public studies refer to studies by academic research groups or studies initiated by governmental and political organs. Eerola (1996) even classifies academic futures research and science fiction literature into this category of technology studies. The common feature of all these public studies is that the information generated is available to a wide audience against a relatively small charge or sometimes even free of charge.

The published national foresight studies belong to public studies, though some of them, for example the UK foresight study, have stimulated private and multi-client studies. It is evident that the information policies of experts differ in private, multi-client and public studies. A firm expert might be ready to transfer his or her best information in a private study but not often in a public study. Eerola (1996) considers that though the most important results of private technology studies are typically internal and confidential information, it may still be advantageous for the company to release some of the results for a wider public. The release may be reasonable in order to strengthen the company's argumentation power when negotiating the financial arrangements, to create a market for new-technology products, etc.

Firms might do an interpretation that national foresight studies are like joint studies: they can be seen as ways to cut down the costs of foresight because individual companies and organizations do not have to pay for the process and its results. Firms might also try to use the studies seriously for building of coalitions for the realization of some options. The problem is of course that unlike a genuine multi-client study a firm cannot communicate only with its potential partners. It cannot exclude competitors from the information. On the other hand, a firm can find some new possible partners which it has not realized before. It can also start after the public study a joint study with promising partners.

How to optimize the sought information in a public technology foresight study? Let us suppose that an expert knows an argument which makes the realization process of a technology generalization feasible for many experts. A reasonable information policy of the expert is to try to maximize positive commitments and to minimize negative commitments of other experts.

If the expert hopes that all other experts will commit to the realization, he or she is ready to transfer the argument as explicitly as possible. Sometimes the argument, however, is the tacit knowledge of the expert or he or she is otherwise incapable to communicate the argument reliably. In an extensive foresight study where opportunities to argument are limited, a reasonable information policy of the expert might be to distribute the information only in the form of standard

proxy arguments. In this special case an index which tells how sure the expert is and possibilities to give e.g. Internet sources for further information might be useful for further argumentation and contacts.

If the expert wishes to exclude some other actors from the information, vague information about the innovation might also be a proper policy. If it is possible e.g. using Internet to make contact with the interested experts, the expert can choose with whom he or she will co-operate. If the expert wishes to exclude all or most others from the information, he or she might, however, give the information in a distorted way.

I think that the use of the Argument Delphi including the use of protagonists and antagonists is an effective further stage of the national foresight studies. The Argument Delphi works properly if positive commitment effects dominate. The domination is in practice possible if the study is focused on a few issues and if all participants see other participants as potential partners. It is reasonable to see the Argument Delphi stages more as multi-client studies than as public studies. The results of this stage should be open to non-participants only if the participants agree.

#### **4.6.4 Active roles of Delphi managers and synthesizers**

Based on the above discussion, I suggest the following partly overlapping stages for national technology foresight processes:

- a) Analysis of developer communities of studied technologies and the selection of core experts based on that information.
- b) Use of core experts in the selection of further experts and the definition of issues and topics in nominal groups or using interviews.
- c) The first "neo-classical" Delphi stage like e.g. in the last Japanese, German or Austrian study (NISTEP 1997, Cuhls et al. 1998, Austrian Delphi Report 1, 1998). The production of proxy-arguments or standard factual arguments and hints for further information.
- d) Possibly the second neo-classical Delphi stage.
- e) Argument Delphi stage.

I call typical two Delphi rounds of existing national technology Delphi studies "neo-classical" because their main features are similar to those of the classical Delphi studies in the 1960s. There is, however, one clear difference between classical and neo-classical Delphi stages: consensus is no longer sought.

The Argument Delphi might replace the second neo-classical Delphi stage or follow it. It can be based for example on those experts who are eager to find

partners for the realization of some specific technology generalizations. The Argument Delphi stage might focus more on commitment reasonability than the neo-classical Delphi stages. The readiness to provide extra information in earlier stages of the foresight process is an indicator of the willingness to participate in the Argument Delphi stage. If similar topics or issues are discussed in technology foresight studies in different countries, it is reasonable to make Argument Delphi stages internationally. In chapter 6, I will discuss some possible features of this type of exercise in more detail.

I suggest that Delphi managers should have an active role in every stage of the process. I already mentioned that a key task in technology forecast studies is to uncover the structures of developer communities. An active role of Delphi managers in a neo-classical Delphi stage is to ask for hints of further information concerning some issue(s), for example the Internet addresses or articles of the panellists.

Because there are few developer communities without controversies or "value parties", relatively neutral and independent Delphi managers are needed for proper analysis and selection of the experts used. It seems to be an advantage if the main Delphi manager is not closely integrated with the developer community of the field studied.

On the other hand, it is highly important that in all phases of the process Delphi managers obtain relevant information from experts. Experts are often not ready to argue seriously with persons whom they do not consider experts. Many consider that active participation in a developer community is a necessary condition for the needed expertise. A feasible solution is to establish a group of Delphi managers which consist of one or more independent researchers and some qualified experts of the developer community studied. At least an advisory board of respected experts is needed.

Beside independent Delphi managers, the role of experts in many topic areas or synthesizers (compare the Chapter 1) is important in the avoidance of the bad effects of information policies. Cuhls and Kuwahara (1994, 2) made this point in the comparative study of German and Japanese technology Delphi studies as follows:

The success of the method depends heavily on the selection of the specialists to be questioned. It must be borne in mind that specialists who are involved in a particular development often tend to rather optimistic estimates. An important *rule* results from this for such surveys: well-informed specialists who are not actively involved in a particular area should be encouraged to express an opinion about that

area... (p.7) Participants who want to shift the group's opinion will assume extreme positions...

It is reasonable that for example in the working groups which make the final selection of the experts used, include generalists or synthesizers as in the latest German national study.

The active role of Delphi managers and synthesizers might prevent biases of the information policies of experts and bad group influences. I consider that Delphi managers should not only be technical collectors and transmitters of the opinions of panellists, but also active synthesizers or even provocateurs in the stage, where issues and topics are formulated in working groups. Delphi managers should support those minority panellists who have presented arguments which other experts cannot nullify. Support for minorities is reasonable because of the typical lag in the public approval of the ideas of minorities. Minorities can at first expect only private change of minds and only later public change of opinions (Moscovici and Personnaz 1980, Avermaet 1995, 365-366). If a minority is not supported, it easily yields or begins to behave in a rigid or dogmatic manner, which makes it less influential (Mugny, 1982).

Delphi managers might try to direct discussion after the first neo-classical stage so that both minority and majority judgements are more closely inspected. Topics with a great dispersion of opinions are especially suitable for further inspection. Based on open-minded but "second best" experts, more relevant information can be sought from the best experts.



## 5. ROLES OF DIFFERENT EXPERT GROUPS IN TECHNOLOGY FORESIGHT STUDIES

### 5.1 Basic Institutions Relevant for Technology Foresight Studies

In this chapter I will examine the competencies and information policies of experts in technology foresight studies, based on an analysis of the rules of the behavior in some basic institutions. I suppose that the information policies of experts depend on three kinds of interacting factors: the personal competencies of expert, the norms of their institutions and the organizers of foresight studies. In this paragraph, I will look at institutions of experts and organizing bodies.

I will look more closely at experts in six types of institutions:

- experts in basic research or in basic education, who represent a developer community or a technological paradigm
- experts in technology generalization organizations of a developer community (for example 'technology push' firms)
- generalization experts in rivaling developer communities
- experts in application organizations of technology generalizations (for example 'demand pull' firms)
- experts in regulative or financing organizations
- consumer stakeholders (e.g. political parties, consumer organizations, environmental organizations, trade unions)

I will divide organizations - typically firms - which use technology generalizations in their products into two basic types: *technology generalization organizations* and *technology application organizations*. Both types of firms do business with products based on technology generalizations specific to a developer community or technological paradigm.

Instead of technology generalization firms Daussage et al. (1992) speak about firms with technology cluster strategies. Firms with a technology cluster strategy (or technology generalization firms) interpret technological potential to be analogous to the business. Businesses are viewed as contingent applications of technological potentials (Daussage et al. 1992, 111). The technology-cluster strategy implies shifting from a financial (allocating resources to businesses) and marketing (concentrating on market share, industry attractiveness, etc.) logic, to a logic based on research and development competencies<sup>1</sup> (Daussage et al. 1992, 114).

According to Daussage et al. (1992,108-109), firms with a technology cluster strategy must systematically look for areas of application where, through their technology, they are likely to offer better performance, value, or quality than the existing products on the market. The firm must be able to assess the competitive advantage its technology could create, and whether this advantage offsets its lack of familiarity with a particular market. The success of a technology-cluster strategy hinges on a firm's selective capacity. This capacity includes both choosing appropriate products and markets, in which to exploit its technological potential, as well as selecting "exploitable" generic technologies which are likely to enhance its technological potential. A competitor who is faster to master and apply new generic technologies thus represents a serious threat, entry into a given industry being a possible consequence of such advantages (Daussage et al. 1992, 111)

Often generalization organizations or organizations applying the technology cluster strategy are multinational corporations (MNCs) or their new ventures. Even without direct links with MNCs the experts of generalization organizations often see the networks of MNCs as their relevant platforms: the networks of sub-contractors, research and education institutes, customers, financiers or public regulators co-operating with MNCs. If an independent research organization works together with a generalization firm for some product based on a technological paradigm, it is also a generalization organization.

While technology generalization firms combine generic technologies for some impacts, application firms have other key competencies. Daussage et al. (1992, 117) mentions distribution competencies, production competencies and "brand image" competencies based on well-known and appreciated products in the market. Technology application firms do not typically develop new technical solutions but try to find most suitable technologies for their special needs from the market. They often use the services of technology generalization firms for that purpose.

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<sup>1</sup> I use the concept "competence" instead of the concept "capability" used by Daussage et al. in order to avoid the misunderstandings resulting from the concept "capability limits" in the general theory of consistence.

Technology generalization firms and technology application firms start the innovation processes typically from "different ends" of the process. Application firms start with the definition of potential products or businesses and, a posteriori, identify technology base as a factor for success ("market pull"). A technology generalization firm starts from its technological paradigm ("technology push").

The competencies and information policies of the technology generalization and application organizations are related in the skills and commitments concerning "paradigmatic languages". Beside *experts in basic research and education institutions*, technology generalization organizations are key developers of any special technological future oriented language discussed in the chapter 2. Any language is shared by experts of a technological paradigm and its developer community. *Generalization experts in rivaling developer communities* do at least partly understand the language of their rivals but they prefer the language of their own developer communities. Also, experts in application organizations have some competence in technological languages on which their applications are based. Because they do not develop new generalizations but only use<sup>2</sup> them, it is enough that they can use them more or less as "black boxes". They are not committed to any specific technological language. Experts of *regulatory or financing organizations* and *consumer stakeholders* can also take many aspects of technology generalizations as black boxes.

Based on the research foresight activities in the 1980s, Irvine and Martin (1989, 27) distinguished seven organizers of research foresight studies:

1. Government advisory boards or central agencies involved in the co-ordination and planning of national science and technology policy.
2. Independent public-sector advisory councils with a broad remit to identify future needs and opportunities for research, as well as potential problems associated with existing policies.
3. Academic funding bodies such as research councils, whose primary task is to support basic science in higher educational institutions.
4. National academies of science and other professional organizations of the research community.
5. Government departments and mission-oriented agencies financing and/or executing work in strategic research and basic technology.

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<sup>2</sup> Any application process is a kind of innovation or technology generalization process. This process is, however, not necessarily based on the paradigmatic language of the developer community. If e.g. a firm uses mobile phones in its activities, it does not need to understand the digital technology used.

6. Industrial associations bringing together groups of companies (often from the same technology sector) to discuss matters of common interest or to collaborate in longer-term generic research.

7. Science-based firms in high-technology fields, many of which have been increasing their investment in strategic research.

We might compare the above mentioned institutions, which had organized technology foresight studies in the eighties, with the institutions discussed in this paragraph. The organizers in group 7 are clearly technology generalization firms making typically private or multiclient studies using the classification of Eerola (1996). In foresight studies organized by industrial associations, technology generalization firms and technology application firms co-operate typically making multiclient studies. The regulation seems to be the typical starting point of the multiclient or public studies organized by government departments.

Academic funding bodies and national academies of science have as the starting points of their foresight activities the norms of academic institutions. Because universities like to find practical and economically profitable applications for the results of their basic research, universities recently co-operate with large technology generalization firms. So the foresight activities of universities are often joint efforts with firms, which means that academic institutions have to take into account the norms of firms. The greatest variety of norms is present in the foresight activities organized by government advisory boards or independent public-sector advisory councils. All national technology foresight studies conducted in the 1990s have been in this category, with the exception of Sweden in the category six. My discussion in this study is mostly focused on these types of public studies.

## **5.2 Different Types of Experts in Basic Institutions**

In the Chapter 3, I defined six types of factual arguments relevant for technology foresight studies:

1. Option-suggesting arguments
2. Arguments concerning genuine invariances
3. Arguments concerning transient invariances
4. Arguments concerning reasons for relevancy evaluations
5. Arguments concerning capacity limits of relevant actors
6. Process arguments.

In principle, it is possible to divide experts in basic institutions according to their expertise in the above arguments. A further aggregation of competencies of ex-

perts might, however, be reasonable. As was more closely discussed in the first chapter, we might speak about *scientists*, *decision-makers* and *synthesizers*. Scientists are experts in invariances. It is reasonable to divide them into *natural scientists* with special competencies in genuine invariances and into *behavioural scientists* with special competencies in transient invariances.

Decision-makers are experts in the use of resources because they can make decisions concerning the use of resources. Any consumer is an expert concerning the use of his or her resources. In organizations, decision-makers are also typically experts in the routines of organizations or in process arguments. The routines of organizations include also decisions concerning information policy. A "routine" is e.g. a decision not to use the information of an expert, if it does not conform to one's own ideas (Innes 1998). The special competence of a synthesizer (or of a generalist) is to see "the whole picture", which defines the reasonability of a technology generalization. He or she is especially competent to produce reasons for relevancy evaluations<sup>3</sup>.

Any expert or organization has a special profile based on the above competencies. An expert might be a decision maker who is a natural scientist but who poorly understands the behaviour of customers. He might work in a technology generalization organization which is also oriented to natural sciences. You can find single behavioural-sciences-oriented experts in technology generalization firms and single technology-push-oriented experts in an application-oriented firm. Often these persons are important links between organizations with different strategies. Besides these *link persons*, the *managers of organizations or corporations with both technology generalization oriented and technology applications oriented units* are often good synthesizers.

The scientific expertise of managers is often, however, superficial as was mentioned by a scientist interviewed by Burgelman and Sayles (1986, 25):

Sure, there are times when research ideas come down from above. An R&D manager may read something in Scientific American, and that gets him interested in a topic. Of course, by the time it appears there, it's already out of vogue in the *real* scientific world.

Often you cannot find the best synthesizers in realizing organizations, as Irvine and Martin (1989,18-19) have remarked. Experts in realization organizations might be suspicious of radical scientific or technological breakthroughs, espe-

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<sup>3</sup> We might make a distinction between the special competencies of decision-makers and those of synthesizers using the concepts of the GTC. Decision-makers are special experts in real (or perceived) capacity limits and perceived capability limits of relevant actor(s). Synthesizers are comparatively good experts in real capability limits. In other words, decision-makers know better, what kinds of decisions will be made based on the recent expertise of decision-makers. Synthesizers are better experts in reasonable decisions.

cially when they run counter to existing research paradigms and conventional wisdom. Parallel problems with this conservatism stem from the difficulties in conceiving novel applications for emerging sciences and technologies. For example, while the development of the radio was successfully predicted, it was seen as a replacement for telegraphy (removing the need for poles and wires) rather than as a means of mass communication. This highlights the importance of creative and counter intuitive thought. A valuable role in technology foresight can often be played by those with broader perspectives such as *futurists*, *journalists* and *science-fiction writers*.

*Administrators or marketers* might be important initiators of demand-pull-based innovation processes. To make the demand-pull approach useful in real technology generalization processes, market needs have to be defined in terms that avoid both overly broad and overly specific needs. Superficial broad needs (e.g. 'materials for home building') might result in science-push generalization proposals, which do not meet the real market demands. Too specific needs (e.g. 'cabinet hinge material') might restrict science-push generalization processes too much (compare Burgelman and Sayles 1986, 39). Too specific a definition of the market demands might hinder new innovations. The success of the Finnish Nokia Corporation in late 1970s in telephone exchange markets is an example where immediate market demands misled competitors like LM Eriksson, which put their resources in old fashioned analogous exchanges instead of digital ones.

An important psychological problem in a demand-pull-based innovation process is often the lack of a "true believer" because the idea is not the "brainchild" of those persons trying to realize it. In contrast, a technical person who becomes a "product champion" of a technology push based innovation process has a sense of being identified with the process (Burgelman-Sayles 1986, 42).

Institutions and positions in institutions have been used to define the types of experts in many national technology foresight studies. In the latest Japanese study, the main activity of the experts was very much based on their institutions: company employee, university related, public servant, other non-company employee, other ( NISTEP1997, 11). In the UK technology foresight study the main activity of respondents was based on positions in institutions. The main activity of experts was divided into the following categories (Loveridge et al. 1995, 21): corporate strategy, marketing/ business management, production operations, academic research, industrial R&D, research management, and other.

In the next sections, I will evaluate the expertise and information policies of the main expert groups in the basic institutions relevant to technology foresight studies. In any section, I first discuss the issue and make preliminary conclusions. Then I will evaluate the preliminary conclusions based on the empirical evidence of the author's studies Kuusi (1987, 1991 and 1994).

### 5.3. Expertise and Information Policies in Technology Realization Institutions

#### 5.3.1 Discussion and preliminary conclusions

A key difference between technology generalization firms and technology application firms concerns the role of generic technologies as assets. It is reasonable to suppose that representatives of technology-generalization firms are typically more reluctant to give information concerning their technological prospects than representatives of technology-application firms. On the other hand, Georghiou (1996, 361) has suggested that firms have become increasingly dependent on complementary or external sources of technology. That is why the formulation of strategy, previously an internal activity, must at least in part be carried out in the public arena. By collaborating in their thoughts about the future, organizations may be better placed to anticipate the actions of their customers, suppliers and others, such as regulators, who are likely to influence the environment, in which they will operate.

Dependence on external sources seems to be reasonable assumption concerning technology application firms. They might be rather ready to present even the technical details of their forthcoming products, because they wish to find new technological solutions for their businesses. But what kind of information policy do technology generalization firms have? Even if large corporations need complementary technologies from other firms, they might not be good sources of information in public technology foresight studies. In the distribution of their best expertise they prefer multiclient studies or the trade of expertise. Based on studies Kuusi (1991) and Kuusi (1994) a group of "second best" experts, which is relatively ready to distribute its best expertise in a public study, are experts *in small relatively independent generalization firms* selling products not yet accepted by mainstream corporations.

Different expert groups in organizations have different interests in sharing information. For the choice of panellists in a public foresight study, an important issue concerns the relationship between organizational information policies and the information policies of single experts.

Burgelman and Sayles (1986, 17) argue that there is an evitable tension between the need of the organization for tangible, commercially profitable results and the need of science to make advances in knowledge. *Scientists in industry* have an interest in making intellectual breakthroughs (which will lead to publishable results) and administrators especially in generalization organizations have often good reasons to be suspicious about the commercial potential of interesting scientific discoveries made by their scientists. Another problem is that the scientist's norms direct work toward projects involving highly specific experiments. On the

other hand, if these experiments are successful, they might have very broad implications (Burgelman and Sayles 1986, 26).

To secure the continuation of his/her technology generalization activity, the scientist is inclined to stress the future prospects of his activity. He/she has a tendency to stress market applications which are straightforward results of research work going on in laboratories. The scientist is inclined to address the needs of atypical users and to invoke their acceptance of the new product, process, or system as evidence for the existence of a new business opportunity (Burgelman and Sayles 1986, 38).

Scientists in industry are not, however, ready to share their visions with anybody. They are enthusiastically shared with other decision-makers in his or her organization because the scientists recognize that the continued funding for their more basic research is dependent upon the enthusiasm of senior management (Burgelman-Sayles 1986, 19). But how to inform members of the technology developer community, which do not belong to the organization?

The scientist usually realizes that sharing information about realized and potential applications of a generic technology has both negative and positive value for their firm and for their future work. A negative value is that present or potential competitors get information about technical achievements or production ideas. On the other hand, the share of information also has positive economic value. Those who get information may be potential customers or partners or their reactions may anticipate how a technology generalization idea will be approved by other experts, or how the potential product will be accepted in market. A generally accepted norm in knowledge barter is that you have to give some information as compensation for the information you need.

The weights of positive and negative values in information sharing differ when

- a) the shared information concerns technical solutions under development and the solutions have not been protected by patents or by other procedures,
- b) the shared information concerns the company's products which are just coming on the market or which are already on the market or
- c) the shared information concerns distant applications of a generic technology.

In the first case, a business scientist does not usually openly distribute the information. In the second case, a possible solution is to deliver information openly but only as much as is needed to convince the customers. If, for example, the quality of a product can be clearly stated without hints to the manufacturing



process, an attempt may be made to retain the manufacturing process as a business secret.

In the third case, at least scientists in enterprises are often ready to behave like scientists in basic research. Some experts, however, consider that a contemplation of distant uses of a generic technology is useless and has only a tiny economic value. Some others think that the free exchange of information is a useful way to find new solutions. They may also think that it is an intellectually exciting enterprise.

Scientific experts in developing tasks in companies sometimes experience difficult role conflicts. In their role as scientists, they have an interest in spreading information about their findings and their favorite theories. In interview situations, the role conflict is expressed by a statement like "I am talking now about confidential matters, do not mention this in your report". A similar type of problem is experienced by business experts whose ethical convictions forbid lying.

It is often difficult to evaluate which level in the organization has the most relevant information about real technical possibilities of technology generalization. Often, the R&D director of a corporation is no longer a real expert in technical matters. The R&D manager of the corporation studied by Burgelman and Sayles (1986, 22) explained this as follows:

You cannot write plans without the experts - and I am no longer an expert. The only thing I can do is to make a resource commitment and describe the scope within which we can then flesh out a program. So what I do is generate and set limits to research "envelopes", but I do not define specifically what goes into them. I can put limits on it, assign priorities, ask questions, go through project reviews, and give policy directions. Remember I have about 50 projects to oversee!

Though lower level R&D persons in large corporations are not necessarily good generalists, they might often be better ("second best") choices for public informants both because of their expertise and their information policy, especially if the anonymity of their answers is secured.

Though *administrators* and *marketers* in realization organizations may also have scientific interests, their main concern is to seek commercial applications to inventions. It is reasonable to suppose, that they see more clearly their expertise as a merchandise than company scientists. If expertise has an economic value, they are ready to deliver it only in barter (information in exchange for other information) or against another type of compensation. If this type of expert does not get an adequate compensation, he or she is inclined to deliver information in a very general form or even in a biased form, as happened in a study of the author.

The assessment of "adequate compensation" is in no way simple. In public studies, the use of adequate economic compensations is usually impossible. Often an adequate compensation is publicity for new products of the corporation. Sometimes adequate compensation might improve image. For example, positive environmental impacts of the new production processes may improve the company's image and its market position.

It is often impossible to get unbiased information from these experts about innovation processes concerning technical solutions under development, if the solutions have not been protected by patents or by other procedures. The possibilities to get unbiased information are radically better if the shared information concerns the company's products which are just coming on the market or which are already on the market or if it concerns distant applications of a generic technology.

Because it is often difficult to get from administrators or marketers relevant information concerning decision-making or potential demand for products, it is reasonable to use "second best" experts such as independent social or consumer scientists. The good expertise of managers can sometimes be used in a way which takes into account the biases in their information sharing. In an expert panel of a future generic technology, a manager of a realizing corporation is often a good evaluator of the economic realism of other panellists. He is especially good in pointing out the weak points in the arguments of competitors of his or her firm.

### **5.3.2 Empirical evidence**

My three technology foresight Delphi studies (Kuusi 1987, 1991, 1994) give some hints at the biases in information sharing concerning technical solutions which have not been protected by patents. Because the answers of experts on the Delphi panels were confidential, the empirical evidence does not reveal the identity of the respondents.

When experts were not ready to give their best information, they used four types of answering strategies:

1. Focusing on other topics
2. Open "no comment" answers
3. Commenting on general level
4. The displacement answer.

If the main objective of a technology foresight study is to produce future options for a generic technology, the first answering strategy produces the most biased answers. This type of bias was met when an administrative research manager of a

large technology corporation used much time in an interview to talk about marginal applications and not about those applications which were intensively studied in his corporation. If an expert uses this strategy he or she can even assert that the topic intensively studied by his organization is irrelevant.

Some firms have given confidential rules to their experts to give "no comment" answers to questions concerning details of their delicate technology generalization processes. If the "no comment" area covers the general ideas behind the planned application, it is a difficult but not as disastrous source of biases as the focusing on other topics strategy. If one is looking at applications which will be realized in 5-20 years, the general idea of an innovation is often a sufficient basis for reasonable discussion about future applications. Moreover a clear "no comment" answer gives a hint to make questions to other experts.

Clearly, the most commonly used strategy of experts in technology realization organizations in the studies of Kuusi (1987, 1991, 1994) was commenting on general level. No expert in the studies ever gave a "no comment" answer concerning some specific innovation, and then refused to discuss the topic on a more general level. An explanation seems to be that firms or their competitors normally had nearby "first generation" products which were just coming on the market or which were already there.

A typical example of the answers on the general level concerned rapid diagnoses based on monoclonal antibodies. The panellists in the study of Kuusi (1991) anticipated that their use will be important in future diagnostics. No specific examples of future applications were, however, given besides the pregnancy tests already on the market at the time of the study. In 1997, the Finnish firm Medix Biochemica received the national export reward based on their 80 rapid diagnosis products. Beside different types of pregnancy tests their products included tests used to diagnose the health of new-born babies. This firm was active in this area already by the time of the interviews (in 1989), but Delphi experts did not mention their activity. An explanation was the "low profile" information strategy of the firm. The managing director of the company explained this strategy in a newspaper interview as follows:

"Our customers are in any case abroad, and so we have kept a rather low profile."

A long time horizon in public technology foresight study is desirable. An important reason is the possibility to use the "displacement effect" in opening future options. By "displacement effect" I refer to a special kind of answering strategy for experts. Its most explicit form was exemplified by a firm-scientist panellist who in an interview openly tried to solve the dilemma of business secrets and option production for the study. The dilemma was that an application of a generic

technology was nearly ready in the expert's firm, but it was not protected by patents or by other procedures. The result of the discussion was that this technology generalization was positioned in year the 2010. This date was more than ten years later than the true anticipated realization time.

## **5.4 Expertise and Information Policies of Basic Researchers and Educators**

### **5.4.1 Discussion and preliminary conclusions**

Unlike in firms, the norms of universities are typically accepted by basic researchers. A recent problem is, however, that some universities might have more unclear norms than earlier because of increased business activities of universities.

Based on their norms, university researchers typically see the transfer of their knowledge as a kind of mission. Many of them adopt an attitude to knowledge as an article for barter (information in exchange for other information) only for unique knowledge (compare Zucker et al., 1995). A genuine basic scientist seldom interprets his knowledge as merchandise.

The best expertise of scientists in basic research concerns general technical possibilities or laws recently found or invariances of nature. The invariances, which a scientist in basic research presents, are usually quite well supported. A scientist also usually presents the reservations which are related to his or her knowledge without a special request.

A scientist in basic research is a good critical evaluator of the scientific information presented by other experts. He or she is often an excellent person to uncover another expert's purposeful hiding or misrepresentation. On the other hand, he or she is typically short of expertise in production costs or the potential market demands for potential new products based on new inventions. Irvine and Martin (1989,19) considered that academics are especially over-optimistic concerning the prospects for the exploitation of their results, in particular the time horizon for commercialization. Irvine and Martin considered that academics fail to anticipate institutional constraints (such as resistance to investing in specialized equipment or infrastructure) or they misjudge the social response to technological developments (for example ethical problems or consumer resistance).

Scientists in basic research can be divided into two types. The first type is careful to present only an invariance which has been successfully established. The information transmitted by this type of scientist is trustworthy but its scope is typically narrow. The second type is directed to syntheses and theoretical generalizations. This kind of scientist willingly emphasizes the development which is con-

nected with his favorite theory, but may ignore the possibility of another kind of technical development. He or she does not often present invalid factual arguments.

Scientists in basic research sometimes have conflicting roles when they are engaged not only in scientific work but also in businesses recently often organized by universities. He/she can also function as a representative of a civic organization. Even a "pure" scientist may experience a role conflict because basic research and commercial applications are nowadays often closely interconnected. As Nelson (1993) has noted, the claim that new commercial technologies have given rise to new sciences is at least as true as the other way around.

#### **5.4.2 Empirical evidence**

What kind of evidence was found in the studies of Kuusi (1987, 1991 and 1994) concerning the behaviour of scientists as members of Delphi panels in public technology foresight studies? The Delphi panels were selected by a co-nomination process started from experts working for applied research especially in VTT (the Technical Research Centre of Finland); in a financing or co-ordination organization for applied research especially in TEKES ( Technology Development Centre of Finland); or in firms. The result was that only a few panellists were real "pure" scientists and even they used to have some experience in technology generalization activities.

The studies provide no clear example of an unrealistic scientist concerning production costs or potential market demands. Actually, if the answers of the biotechnology study given in 1989 are compared with the real situation in 1999, it seems that experts from universities and public health research institutes made better evaluations e.g. concerning the turnover of diagnostics business (typically 100-300 MFmk) than the representatives of firms (typically 300-500 MFmk).

As was discussed in the chapter 3, the prediction reasonability of evaluations is not necessarily compatible with the true epistemic utility of choices (or other types of reasonability). Unlike the study concerning new materials (Kuusi 1994), the biotechnology study (Kuusi 1991) did not make an attempt to evaluate the type of reasonability of evaluations. The above result at least shows, that basic researchers were not overoptimistic in comparison with firm experts, as was suggested by Irvine and Martin (1989). If we could use the prediction reasonability as the proxy indicator of the general reasonability, at least in this case the criticality of scientists without close connections to business, was more relevant for realistic evaluations than the practical expertise of business experts possibly biased by business related information policies of technology generalizing firms.

Clear examples of the above mentioned two types of university scientists were found. The "narrow mind" type of university scientists made focused comments in the studies Kuusi (1991) and Kuusi (1994). Some scientists working in the areas of animal biotechnology, plant biotechnology and ceramic materials gave detailed and informative comments concerning their specialties but were not eager to comment on other areas. On the other hand, there were enthusiasts of new biotechnology and of new tailor-made materials who were ready to comment on nearly all types of applications of generic technologies discussed. Many of the best synthesizers were found in the national research institute VTT, which is "between" basic research and firms.

The critical role of a scientist was best exemplified by a company scientist specialized in conventional plant breeding activities instead of the use of new gene technology. He transmitted much material to the Delphi managers concerning the possible dangers of the use of gene technology in the breeding of plants and also in other application areas.

The conflicting roles of scientists did not result in very difficult problems in the studies because the topics were discussed on a rather general level. The scientists of public research institutes or universities function as good control persons for the scientific realism of promising application areas proposed by other experts.

## **5.5 Expertise and Information Policies in Institutions of Rival Technologies**

### **5.5.1 Discussion and preliminary conclusions**

Like the experts of the generic technology discussed the experts of rival technological paradigms can be divided into basic researchers, educators, experts in technology generalization or application firms, experts in regulative organizations and representatives of consumers. Experts in the application firms of the discussed technology and experts in the application firms of rival or complementary technologies do not differ considerably because of common application areas. The same also concerns experts in regulative organizations and representatives of consumers. On the other hand, the expertise and interests of basic researchers, educators and experts in technology-generalization firms differ considerably.

If an expert of a rival technology is also an expert in the discussed technology he or she is a potential excellent critic. His or her critic may, however, be biased. Like an expert of a generalization firm of the discussed technological paradigm, he or she realizes that information sharing has both negative and positive commitment effects. The negative commitment effect is that competitors get information for the further development of their rival products. On the other hand, the

sharing of information might also have positive commitment effects. Those who get information might be potential customers or partners or their reactions may anticipate how a technology generalization idea is approved by other experts or how the potential product will be accepted by the market.

The sharing of critical information with application firms is reasonable if the technological paradigms can substitute or complement each other in the products of application firms. If the technological paradigms might complement each other like metal materials and polymer materials in composite materials, the exchange of information between firms with different technological paradigms might be very reasonable. It is even possible that the paradigms will be merged.

Scientists in the basic research of the rival technology have different information policies than company scientists. An expert in basic research directed at the syntheses or theoretical generalizations might be more interested in communication than narrow-minded specialists. In the case of complementary technologies, the biases resulting from the information policies might be less urgent.

### **5.5.2 Empirical evidence**

In the studies of Kuusi (1987, 1991, 1994), the role of rival experts was important especially in the study, which was focused on future polymer materials (Kuusi 1994). Rival experts were experts in metals and in ceramic materials. A problem was evident already in the beginning of the study: the scientific developers of polymer or plastic materials and the scientific developers of metal materials were not familiar with recent developments in rival materials. The attitude of some scientific developers of metals was defensive concerning the future possibilities of advanced polymer or polymer composite materials.

## **5.6 Expertise and Information Policies in Regulative or Financing Institutions**

### **5.6.1 Discussion and preliminary conclusions**

Experts in public regulative or financing organizations can in many ways contribute to the diffusion of a generic technology. They transmit information and ideas to political decision-makers. Regulative or financing organizations often have direct influence on infrastructure decisions. Most of them decide on loans and on support for generalizations and applications of technologies.

Norms of regulative institutions are in a favour of the provision of open information concerning existing regulations and the reasons for regulations. Experts of

these institutions are usually ready to tell about regulation or technology infrastructure alternatives extensively even at the early preparation phase because they like to be aware of possible effects and reactions on different choices.

Civil servants are often good arbitrators of interests because they often have extensive contact networks in a developer community and because they are often considered to be more neutral than other expert groups. Sometimes, the experts in the banking sector have played a similar role as an arbitrator.

### **5.6.2 Empirical evidence**

In the studies of Kuusi (1987, 1991, 1994), experts in public regulative or financing organizations had an important synthesizing role. The organization behind the first study (Kuusi 1987) was the Finnish Government Consultative Committee of Information Technology. The General Secretary of the consultative committee was an expert who knew the experts working in the field in Finland. He was also capable of making many useful synthesizing comments. The similar role in the New Biotechnology study (Kuusi 1991) was played by both experts at VTT and by an expert who was responsible for the area of genetic engineering in Technology Development Centre of Finland (TEKES), responsible for the public funding of technology in Finland. In study Kuusi (1994), the role of experts in waste management working in the Ministry of Environment was more specific. They gave useful comments concerning the forthcoming national and EU regulation of waste management.

## **5.7 Expertise and Information Policies of Consumer Stakeholders**

### **5.7.1 Discussion and preliminary conclusions**

The Austrian foresight report remarks that "the most foreign studies have focused on the supply side of the technology" (Delphi Report Austria 1, 50). For example, it often happens that developers of a new technology are men, though the majority of the planned future "consumers" of the technology are women. The lack of consumer stakeholders in expert panels explains at least partly the fact that the share of women has been very low in national technology foresight studies. In joint German-Japanese Delphi study, female participants in the Japanese study accounted only 1-2 percent and in the German study four percent (Cuhls and Kuwahara 1994, 19). Besides the genre-distributions, the age distributions of participants used also to be rather biased. In the UK study, panellists younger than 30 years accounted 1% (Loveridge et al. 1995, 21). The highest share of women was achieved in the Austrian study, where it was 12,5%. The share of panellists younger than 30 years was also in comparison with other studies high:



3,9% (Delphi Report Austria 1, 74). This indicates that the Austrian study was taken more seriously than other studies the task of selecting experts who can evaluate the "consumption" of technologies from the point of view of earlier neglected groups of people. The shares of women and young people were, however, still low even in the Austrian study.

The large share of men and middle aged or older panellists might be a reasonable choice based on expertise on arguments concerning technical feasibility or main impacts of technology generalizations. Before there are first realized applications of a technology, even the anticipation of negative side effects or side impacts requires the technical competence. Men at least in middle ages might be best in this competence, but established experts are often in lack of critical mind of their younger or women colleagues.

In any case, the evaluation of the relevance of impacts needs, however, feedback from consumers or from "ordinary citizens". Often consumers are suspicious about the suggested impacts of products. Instead of irrational conservatism, this skepticism is sometimes proved to be a very reasonable attitude. Consumers know old products and they have often seen that new products do not meet their suggested promises or produce unanticipated side effects like the nuclear energy. Often consumers want to continue their old habits with new products. This is relevant especially for food, as e.g. Pantzar (1992) has shown in the competition between butter and margarine in Finland.

How can experts for the evaluation of the "consumption" of technologies be found? A solution is a survey like that of the Austrian foresight study (Delphi Report Austria 1, 1998), where average consumers evaluate possible trends in technological development. The problem is, that it is very difficult to present potential technology generalizations in a way, which help average consumers to make well-informed choices. I think that a better solution would be to use better informed consumer stakeholders.

It is, however, not easy to select proper consumer stakeholders. Workers of consumer organizations or environmental organizations might be good experts regarding potential consumer or media reactions to new products and regarding their effects on health or environment. Sometimes these organizations have even succeeded in obtaining a ban products which public authorities have already accepted. Another choice is to use representatives of political parties. Beside expertise in the relevancy evaluations of ordinary people, they have decision-making expertise based on their connections with political decision makers.

A recent Delphi study which has taken the consumer point of view into account, is the international Delphi Agro-Food made in Germany, Netherlands, Italy, Spain and Greece (Menrad et al. 1998). The study anticipates the future use of

new biotechnology in agriculture and in food industry. The national panels of the study included six expert groups: industry; research institutes; farmers; consumers or users; critics of biotechnology and experts in social impacts of biotechnology; and other experts (e.g. politicians, regulators, educators, journalists, patenting experts). (Menrad et al. 1998, 8).

Evaluations of experts from industry or research institutes differed considerably from evaluations of consumer stakeholders and critics of biotechnology in the German study. For example the differences of evaluations were considerable concerning the following topic: "Proteins, which are optimized using protein engineering, will be used in different sectors of food industry". About 70% of experts from industry or research institutes and only about 30% of experts representing consumers or critics have a positive opinion concerning this development<sup>4</sup> (Menrad et al. 1998, 19 and 89).

### 5.7.2 Empirical results

In the study of Kuusi (1987) concerning future Internet-like information services representatives of labour unions were used as consumer stakeholders. They seemed to be the reasonable choice, because they actively participated in the preparation of the "Finnish information society program" of the Finnish Government Consultative Committee of Information Technology and were important for the core customers of the study. No special consumer stakeholders participated in the new biotechnology study (Kuusi 1991). The reason was that basic expertise in methods of genetic engineering was needed. It was assumed that experts e.g. in public health organizations, could represent the interests of consumers. Based on aggressive discussions in 1990s in media and in the political arena, the lack of special consumer stakeholders was an evident weakness of the study. The mistake was partly corrected by the information obtained from some panellists concerning movements against genetic engineering.

The mistake of the study of Kuusi (1991) was corrected in the study of Kuusi (1994). From the beginning of the research process, the participation of consumer stakeholders was noted. The consumer stakeholders in this study concerning future polymer materials were persons who had actively developed the environmental policy of the Finnish Nature Conservation Association.

The consumer stakeholders, who participated in the study Kuusi (1994), typically argued that they had a scientist-like open attitude to distribution of information. They seemed, however, to have a subconscious or sometimes conscious aim to

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<sup>4</sup> About 200 experts belonging to the first class and about 100 experts belonging to the second class commented the topic.

transmit mainly the information supporting the aims and ideas of their organization. In the beginning of the research process their expertise in new technical developments relevant for the future of polymer materials was usually rather limited, but they were eager to take into account the comments from other experts. At the end of the process some of them were excellent synthesizers and useful for the final report of the study.

The consumer stakeholders in the study of Kuusi (1994) were active ethical evaluators of alternative futures; they were eager to assess the ethical validity of the arguments of representatives of other groups. They reacted intensively against the breakers of generally approved norms against dishonesty or the narrow pursuit of self-interest.



## **6. HOW TO USE THE ARGUMENT DELPHI?**

At the end of the Chapter 4, I suggested that an Argument Delphi stage might follow the neo-classical Delphi stages in national technology foresight studies. I suggested that the Argument Delphi stage should be based on those experts who are eager to find partners for the realization of some specific technology generalizations. When the focus in the earlier stages of the foresight process has been largely on option reasonability, the Argument Delphi stage might concern more the commitment reasonability besides identifying more specific options. Because similar topics or issues are discussed in technology foresight studies in different countries, I suggested that it might be reasonable to make Argument Delphi stages using international panels.

In this chapter, I will elaborate the idea further based on experience from the studies of Kuusi (1987, 1991 and 1994). The experience from these studies might be useful if the Argument Delphi stages are made using small international panels of 30-50 persons. In the Argument Delphi studies, the focus should be very specific: an issue area or a single issue.

I will discuss three hypothetical Argument Delphi studies. The idea is to connect some issues of my studies with similar topics of the national studies, and to focus the discussion on some questions relevant for any Argument Delphi exercise.

### **6.1 Core Customers in the Study of Households Computer-Based Information Services**

#### **6.1.1 Techniques, impacts and developer community related to a topic**

The fourth Japanese foresight study included the following topic (IFTECH 1988, 52):

Widespread use of home computer systems useable as information system terminals as well (for control of home equipment, management of household finances and family health, and use as dialogue-type study aids).

A reasonable conclusion is, that this topic is already realized based on the use of Internet. In the present situation we can evaluate the results of Kuusi (1987) and the imaginary Argument Delphi stage of IFTECH 1988 also from the perspective of realized developments. Let us suppose that the Japanese study would have had an Argument Delphi stage and experts would have been eager to organize an Argument Delphi exercise around the topic. In the present situation, the use of Internet and e-mail is a reasonable way to accomplish the exercise, for example using the Professional Delphi Scan software (<http://delfoi.ofw.fi>). Let us suppose that the organizers of the fourth national study would have selected a Delphi manager or managers to organize the Argument Delphi process.

The topic is a technology generalization proposal based on the rather broad concept (or paradigm) of information technology. A first job of the manager is to clarify it and to relate it to the other topics of the study or to the issues of other foresight studies. The definition of technology generalization arouses two questions:

- What are the specific techniques (motivated by technological paradigms), which are related to the topic?
- What kinds of relevant impacts (motivated by technological paradigms) can be produced?

The selection of the relevant topics based on the above questions might be based on a special working group or on a voting process of interested panellists of the earlier stages of foresight studies. The Japanese study includes at least five related topics including ideas about possible techniques (IFTECH 1988, techniques italicized by me):

1. Widespread use of same cards with *imbedded microprocessors and memories* (CPU cards) for access control, purchasing, banking and telephone fee payment etc. (p.42)
2. Completion of international integrated services *digital* networks (ISDN) covering virtually all countries, with automatic access from domestic ISDN. (p.214)
3. Practical use of electronic mail communications systems offering reinforced confidentiality through use of *identity verification technology based on fingerprints, signatures, or voiceprints*. (p.214)
4. Widespread use of electronic newspapers *transmitted by satellite or ground broadcasting* (scrambled in form only subscribers can descramble). (p.216)

5. Widespread use of remote medical care systems applying *computer tomography, ultrasonic waves, infrared image transmission equipment, high-resolution monitor systems, and biosensors*. (p.218)

The topic discussed mentions some possible applications resulting from the generalization or application of information technology for household information services. Further possible applications related to impacts of the techniques are mentioned in other topics (applications italicized by the author):

1. Widespread use of *same cards* with imbedded microprocessors and memories (CPU cards) *for access control, purchasing, banking and telephone fee payment etc.* (p.42)

2. Development of *multimedia data base systems capable of storage and retrieval of text, drawings, images, and voice data in an organic interrelationship*. (p.58)

3. Widespread use of *highly reliable security systems to eliminate leakage of information or invasion of privacy for individuals or groups*. (p.60)

4. Practical use of *local area networks with speeds exceeding 10 Gbps*. (p.211)

5. Practical use of electronic mail communications systems offering *reinforced confidentiality* through use of identity verification technology based on fingerprints, signatures, or voiceprints. (p.214)

6. Widespread use of *electronic newspapers* transmitted by satellite or ground broadcasting (scrambled in form only subscribers can descramble). (p.216)

7. Realization of *production-order-delivery systems enabling customers to order merchandise designed to their preferences and have it delivered on a short time basis, all while remaining at home, based on integration of small-lot, high-diversity production facilities, sophisticated conveyance systems, and high resolution terminals*. (p.218)

8. Development of *anti-hacker devices capable of detecting abnormal access or signaling/receiving based on knowledge acquired (i.e. learning) about past unauthorized access*. (p.220)

After a preliminary collection of the related techniques and impacts relevant for the topic, the next phase is to look after the panellists of the Argument Delphi. Though the interested experts of the topic and the above related topics provide a good starting point for the Argument Delphi, the Delphi managers should analyse the developer community of the topic more closely. Especially the identification of core customers of the study is a crucial task.

The analysis of the developer community can be based on the identification of the basic institutions and special types of expertise related to the topic or to related issues. It is possible to use classifications of institutions and special types of expertise given in Chapter 5

*The classification based on institutions:*

- experts in basic research or education
- experts in technology generalization organizations (e.g. 'technology push' oriented firms)
- experts in rival developer communities
- experts in application organizations of made technology generalizations (e.g. 'demand pull' oriented firms)
- experts in regulative or financing organizations
- consumer stakeholders (e.g. political parties, consumer organizations, environmental organizations, trade unions).

*The classification based on the special type of expertise:*

- natural scientists
- behavioural scientists
- decision makers
- synthesizers.

I think that it is useful to make a rather detailed analysis of participants and their expertise for an Argument Delphi process; otherwise the peculiarities of the developer community focused on will not be noticed and taken into account in the argumentation process. As an example, I will analyse in Appendix 2 the panellists of the study Kuusi (1994).

### **6.1.2 Core customers and the selection of expert panel in the study concerning computer based information services for Finnish households**

The study of Kuusi (1987) focused on future computer-based information services for Finnish households. It was a Delphi study with two rounds having some features of the Argument Delphi e.g. personal interviews in the first round. Though this study was not a real Argument Delphi exercise because of the lack of a real factual argumentation stage, it gives a practical illustration of how selection of the panellists can be based on the identification of core customers.

The members of the panel were selected by a working group of experts, which belonged to the Consultative Committee of Information Technology. This committee



was also the organizer of the study. The selection of the 26 panellists was not based on any explicit method or standards devised in advance. The structure of the developer community was not explicitly discussed though the representation of the different stakeholders of the developer community was an implicit starting point. The next argument illustrates, however, a stage, which seems to be reasonable in any Argument Delphi process before the selection of the panelists: *the evaluation of the relevancy of different stakeholder groups for the study* (Kuusi, 1987, 44):

The banking sector was well represented in the Delphi panel. This choice is motivated by the fact that this sector is presently by far the most important sector of computer-based information services used by households [in Finland]. A structural change is going on in this sector, which might have a substantial impact on employment. The banking sector is seeking new functions. At least in principle, many of the computer-based information services discussed in this report can provide that type of new functions.

I think the Argument Delphi process is more useful if there are core customers in the argumentation process. In the Finnish study, the core customer was clearly the banking sector. A core customer represents in a way the "main bottleneck" in the innovation process of the topic discussed. In this case, the main bottleneck seemed to be more applications, not so much techniques. Core customers are also key experts in commitment processes. In practice, rival experts can be defined based on their relation to core customers (and their technological paradigm).

If we evaluate the choice from the perspective of the development realized, the choice of the core customers was very reasonable. The new communication technology has had dramatic impacts on the Finnish banking sector. Besides the economic crisis of the Finnish banking sector in 1990s, the new communication technology provides the main explanation for the following dramatic changes. The number of bank employees was reduced from 54 000 in 1989 to 29 000 in 1997. The number of bank offices was reduced from 3500 to 1600 in 1998 (Aro 1998).

The panel can be described to be based largely on the relation of the panellists with the core customers

Core customers:

- 7 decision-makers in application organizations (developer managers of computer-based information services in banking or in insurance).

Other experts:

- 3 experts in technology generalization organizations, more synthesizers or decision-makers than scientists (persons working in firms or institutions producing or selling computer-based information service equipment typically used by banks or by their competitors in information services)
- 4 behavioural science oriented experts in rival or complementary application organizations (consultants in information services)
- 2 natural scientists in basic research or education (professors in information technology)
- 4 decision maker-stakeholders of users of the technology (information technology experts in trade unions representing bank clerks and other employees, which provide information services)
- 1 regulating expert (an inspector of the telecommunication area working in a ministry)
- 5 synthesizers or consumer stakeholders (the general secretary of the Finnish Government Consultative Committee of Information Technology, a member of the Finnish Parliament specializing in media issues, three behavioural-science-oriented media experts, one of them a journalist)

The topics of the Finnish study are presented in table 6.1. The panellists were asked to evaluate which five topics will be most important in 1996 and in 2010. The services are presented in order of importance, based on the share of panellists, which included the service among the five most important services in 1996. It is important to note that the evaluation is based on the use of services both in homes and also in self-service at public places (for example the use of cash dispensers) and service (for example the use of bank clerks).

Table 6.1. *The most important household computer based information services*

	Share of panellists including the topic among the five most important in 1996 %
1. <i>Withdrawal of cash</i> including the use of intelligent bankcard, does not include the use of on-line cash card.	100
2. <i>Paying of bills.</i> The person accepts the bill with a signature or number code. Does not include the use of on-line cash card.	100
3. <i>Selling or reservation of tickets</i> for trips or for other purposes (e.g. theaters)	58
4. <i>Search for job options</i>	50
5. <i>Search for literature</i>	46
6. <i>Electronic mail</i> used for hobbies of households or for interaction between households	46
7. <i>Search for investment options</i> (e.g. subscribing of shares )	35
8. <i>Search for durable goods</i> (e.g. cars and machines)	27
9. <i>Search for dwelling options</i>	16
10. <i>Diagnoses of diseases</i>	8
11. <i>Search for detailed information</i> on different types of practical jobs (e.g. home repairs)	4
12. <i>"Personal" newspapers</i> collected from different sources	4
13. <i>Households' communication abroad</i> using computer networks	4
14. <i>Leaving information for taxation</i>	4
15. <i>Search and selling of parts</i> for e.g. cars and household appliances	0

As option-suggesting arguments, the topics discussed in the Finnish study described the final impacts of technology generalizations. They were, however, poorly formulated from the point of view of promising techniques for technology generalizations. With only a few exemptions, a general assumption was made that in 1996 there will already be a general network of computers including household computers which will provide the services requested.

### 6.1.3 Some remarks concerning the predictive reasonability of the study

In chapter 3, I gave two necessary conditions for the prediction reasonable generalization b:

- (1)  $I_b F_b V_b R_b A$  is over  $L_A$ , where A is the group of actors whose actions are decisive for the realization of b
- (2) b is reasonably relevant for the group of customers of a prediction study.

The identification of core customers gives a practical interpretation of the second condition. We might consider that the main group of customers of the study was the Finnish banking sector.

Related to the first condition, the study provides examples concerning the connection between powerful actors and the realized future.

A special focus of the study was the use of service or self-service in future, which was a highly important question for the core customers of the study. Concerning every topic three possibilities to use the service were given:

- service
- self-service at a public place and
- self-service at home.

In the case of cash withdrawal, the possibilities meant the use of a bank clerk, the use of a cash dispenser or the use of a home computer. Concerning the first condition of the prediction reasonability, predictions of different stakeholders concerning the cash withdrawal are interesting. The proportion of service and self-service in this topic is mainly a result of the interaction process of three kinds of stakeholders: decision-makers in banks, bank clerks and bank customers. These stakeholders were well represented in the expert panel.

A working technique for self-service in cash withdrawal at a public places was already in use in Finland in 1986. In that year, cash dispensers accounted for 6% of transactions. The basic technology of cash dispensers in 1986 did not change very much in 1986-1996. The intelligent cash cards, which function as cash, were introduced extensively in the beginning of 1998 in Finland.

Concerning the cash withdrawal decision-makers in banks made better predictions than stakeholders of bank clerks or bank customers. The distribution of the responses of bank experts concerning the use of cash dispensers in 1996 was very small, the distribution range was 50-70 % and the median 60%, which seems to be rather near the right number.

The range of the answers of other experts was 10-80% and the median 40%. The representative of the labour union of bank executives and their umbrella organization shared the vision of decision-makers, although other workforce stakeholders (for example representatives of public telecommunication administration and other labour unions) estimated the proportion of bank dispensers to be less than thirty percent in 1996. Other experts generally consider that negative employment effects concerning bank executives would hinder the increase of the share.

In reality, the depression of the Finnish banking sector in 1990s resulted just in the dismissal of bank executives for economic reasons. We might conclude that decision-makers in banks were able to make their mind also concerning the use self-service. They were more or less the "group A" in the first condition of the prediction reasonability.

The decision-makers succeeded relatively well in predicting cash withdrawal based on established techniques but not in the anticipation of a new technology. The impacts of the World Wide Web were not anticipated by the panellists. Only one panellist, a university professor in information technology, estimated that the households' communication abroad using computer networks will be one of the five most important computer-based household services. Finnish households were, however, world's top users of the Internet in 1996.

## **6.2 How to Describe a Technological Paradigm for Argument Delphi: the Case of New Biotechnology**

The Argument Delphi is essentially based on the systematic production of factual arguments based on rival technological paradigms. In this section I will try to give some preliminary suggestions concerning a difficult question. How should the basic features of some technological paradigm be described to help the argumentation process concerning rival or complementary technology generalization proposals based on different technological paradigms?

This discussion is focused on the paradigm of the genetic engineering or the new biotechnology discussed in the study Kuusi (1991). A practical future application area, which might benefit from my discussion is the development of solar energy. Kerstin Cuhls (1998, 207) has presented a kind of relevance tree concerning targets or impacts related to solar energy. To really understand - not only to believe based on the "proxy arguments" or tacit knowledge of experts - in an Argument Delphi process, what impacts are possible, we need to understand the basic features of technological paradigms that might produce the impacts. For example, if we like to understand the technological paradigm of the production of solar energy based on bacterial rhodopsin, we have to understand the basic paradigmatic features of the new

biotechnology. This paradigm differs considerably from the paradigm used in the development of silicon cells.

I proposed in Chapter 2 that the Bonsai tree is a good way to describe a technological paradigm. A technological paradigm changes continuously as the result of learning processes. An important result of an option-seeking technology Delphi process can be the "enrichment" of the technological paradigm or its Bonsai tree. The finding of relevant new branches (promising new product areas), blades (promising new products) or new roots (promising new technologies) can be seen as an important contribution of a technology foresight study.

A technological paradigm is a social construction of many actors. At some point of time, the actors have different mental pictures of its key features. It is, however, afterwards possible to see better what the key features of the paradigm in the past "ideally" were. That type of evaluation can be based on the features of the paradigm, which have later resulted in the most important applications or technology generalizations.

The following description of the world-wide "ideal" technological paradigm of the new biotechnology in 1989-1990 is based on successful generic technologies and important product areas. The description is on a rather general level. The focus is in successful generic technological ideas and product branches. The successfulness is based on evaluations made about five years after the Delphi study. All discussed generic technological ideas and product branches were already known by the key actors of the new biotechnology developer community in 1989-1990.

As "measures" of successful generic technological ideas and product branches, I have used three survey books of new biotechnology published in 1994-1996 (Wilson and Walker 1994, Moses and Moses 1995, Watson et al. 1996). Actually, nearly all the generic technological ideas and promising product branches discussed in these survey books were already known in 1989-1990, when the interviews of the study Kuusi (1991) were made.

I start the analysis of the "ideal" paradigm of new biotechnology from the technology-push side or from the "roots" of the bonsai tree. In specifying key generic technologies of the new biotechnology in 1989-1990, it is important to realize at least on the general level all the basic technologies in use at that time in biotechnology. This type of "checking list" can be made by looking at the book "Principles and techniques of practical biochemistry" (Wilson and Walker 1994). In its 586 pages also the basic methods of genetics and microbiology are described in addition to biochemistry. A simple way to proceed in the description of the technological paradigm is to look at the headlines of the book. The book is divided into eleven chapters and these chapters are divided in 123 subchapters and these further in 307 subsubchapters. Excluding the first chapter ("General principles of biochemical investigations")

the other ten chapters can be interpreted to suggest generic technologies or their clusters.

I started the search process at the roots of an "ideal" Bonsai tree by making a "checking list" of headlines of chapters and subchapters of Wilson and Walker (1994). This list was evaluated by the professional biochemist who was the key person in the formulation of product branches used in the Finnish biotechnology Delphi study. She evaluated the present importance of different generic technologies. Based on her evaluation, the most promising biotechnology generic ideas proposed by Moses and Moses (1995, 272-273) and the other above mentioned sources, I have divided the "roots" of the "ideal" Bonsai tree of new biotechnology of 1989-1990 into key technological generic ideas, base generic ideas, pacing generic ideas and emerging ideas using the classification of Arthur D. Little (Irvine and Martin 1989, 94-95), which was discussed at the end of the paragraph 3.8.

The classification of generic ideas is of course only for illustration. In practical Argument Delphi processes, both the formulation of generic ideas and their classification into the categories can be made with experts. They might comment on suggestions made by Delphi managers based on interviews with experts.

Short motivations for the paradigmatic ideas are presented in Appendix 3. Ideas are marked for further discussion. I use in the appendix italics with the code numbers (B1, B2,..., K1, K2,..., P1, P2,... E1, E2,...) to mark important generic ideas, which are summarized below. The letter B refers to a base generic technological idea, K to a key generic idea, P to a pacing generic idea and E to an emerging idea. I use the same code number to closely related generic ideas. Important generic subideas are marked by a,b,... (e.g. B1a, B1b, ...).

***The summary of the generic ideas of the "ideal" paradigm of the new biotechnology.***

Key generic ideas of the new biotechnology in 1989-1990

Techniques to allow the transfer of genetic information from one species to another to another species or methods that make possible *for a cell to accept a strange string of DNA, which codifies the production of a protein (K1)*

In certain chemical environments, animal cells will take up DNA from the environment, just as bacteria do. The process can be helped by *applying an electric current (K1a)*

*Microinjection (K1b)* to inject a DNA-solution directly into animal cells

To incorporate the DNA into certain *viruses which are allowed to infect the animal cells (K1c)*.

It is sometimes possible to persuade cells from different animals to fuse together, resulting in *cell hybrids containing the string of DNA codifying the sought protein(K1d)*.

In the technique of particle acceleration, the *DNA to be transferred is coated onto minute gold particles which are fired at target cells (K1e)*.

*Cell fusion (K2)*. Fused cells contain the nuclei - and hence the genetic information - of both fused cells.

Cloning technology was made by fusing antibody producing cells with cancerous lymphocytes (myeloma cells). The products are called "*monoclonal antibodies*" (*K2a*) because it is produced as a single, pure substance from a single clone of cells.

Routines to *sequence any newly isolated DNA fragment of interest (K3)*

*Automated sequencing techniques (K4)*

*Gene libraries (K5)* are constructed by isolating the complete genomic DNA from a cell, and cutting it almost randomly into fragments of the desired average length.

*Protein and enzyme techniques (K6)* to uncover

*primary structures (K6a)* (sequences of the amino acid residues),

*secondary structures (K6b)* (localized folding of polypeptide chain due to hydrogen bonding),

*tertiary structures (K6c)* (the overall folding of a polypeptide chain, which is stabilized by electrostatic attractions and by weak van der Waals' forces) and

*quaternary structures (K6d)* (associations of two or more polypeptide chains).

### Base generalization ideas of the new biotechnology in 1989-1990

*Fermentation and cell and tissue techniques (B1)*

*Light and electron microscopic (B2)* examination of tissue, cell or organelle preparations to evaluate the integrity of samples and to correlate structure with function.



*Radioisotopes (B3)* have been very widely used in the study of the mechanisms and rates of absorption, accumulation and translocation of inorganic and organic compounds by both plants and animals.

*Centrifugation separation techniques (B4)* are based upon the behaviour of particles in an applied centrifugal field.

*The recognition of the variety of types of spectrum (B5).*

Components will have been separated according to their *electrophoretic mobility (B6)*.

*The choice of stationary and mobile phases is made so that the compounds to be separated have different partitions (B7)*

#### Pacing generalization ideas of the new biotechnology in 1989-1990

*Polymerase chain reaction technique (PCR)(P1)*

New very effective microscopes *Scanning Tunneling Microscope (STM)* and *Atomic Force Microscope (P2)* can discern even single atoms.

Performing the kind of experiment that causes the molecular entity to disintegrate and produce fragment *ions each of which is represented by a peak in the result spectrum (P3)*.

*A biosensor (P4)* is an analytical device consisting of a biocatalyst (enzyme, cell or tissue) and a transducer, which can convert a biochemical signal into a quantifiable electrical signal.

#### An emerging generalization idea in 1989-1990

*Any double-stranded polymer with completing strands is a potential target for multiplication (E1).*

How can the above generic ideas be used in the Argument Delphi process? My idea is that if we have these types of descriptions of technological paradigms we might argue about topics in a more coherent way. The argumentation can be based on coded basic arguments instead of written arguments. If the Internet is used, any code might have a hyper-text link to a file where the basic argument is more closely elaborated.

I can illustrate my idea with generalization proposals presented by Moses and Moses (1995). The final chapter of Moses and Moses (1995) was entitled "The future: biotechnological bonanzas?" In that chapter, the authors present a summary of future promising technological generalizations (Moses and Moses 1995, 272-273). It is possible to motivate these options with the key generic ideas of the "ideal" paradigm.

Technology generalization proposals and their motivation:

A. The Human Genome Project will undoubtedly make available enormous amounts of information of profound significance for understanding the human condition and some its defects. (K3,K4,K5)

B. With this and other new knowledge, progress in the techniques of genetic manipulation will permit new forms of therapeutic treatment. (K1,K3, K4,K5)

C. Greater insight into molecular biology and developmental genetics will greatly add to an understanding of degenerative and neoplastic diseases, hopefully leading to more effective therapies. (K1,K2, K3,K4,K5, K6)

D. Parallel progress in plant genetics and the manipulation of plant material will enable new forms of crop plants to be developed, perhaps allowing field crops to be used as more convenient and lower cost factories for animal proteins than microbial systems in fermenters. (K1, K3,K4,K5, K6)

E. Advances in the biochemistry and genetics of nitrogen fixation should reduce the demand for nitrogen fertilizer while biological pest control might in time offer a variety of effective and environmentally acceptable means of such control. Together they will improve the efficiency of agricultural production. (K1, K3,K4,K5, K6)

F. Developments in protein engineering are likely to offer not only better but also new enzyme catalysts: "better" in the sense that they are more robust, survive higher temperatures and harsher conditions, and last longer in service; "new" by being able to catalyse reactions unknown in biochemistry and hitherto inaccessible to biological catalysis. (K6)

G. The recent discovery of extremely thermotolerant and other previously unknown bacteria offers the prospect of using microbiological procedures in environments too hot, too acid or too salty for the more familiar species. (K1)

### 6.3 The Problem of Pacing or Emerging Generic Ideas in the Argument Delphi Processes

If we compare the previous analysis of the "ideal" paradigm of the new biotechnology 1989-1990 with the actual suggestions made by Finnish experts in the study Kuusi (1991), there is an interesting difference. Watson et al. (1996) considered that the polymerase chain reaction technique (PCR) devised by Gary Mullis in the mid 1980s has revolutionized molecular genetics by making possible a whole new approach to the study and analysis of genes. This pacing generic idea of the "ideal" paradigm of 1989-1990 is now clearly a key generic idea of genetic engineering. It was not, however, mentioned in the first round interviews or in the second round arguments of the biotechnology Argument Delphi. The generic idea with its extensive implications was noticed not until the third commenting stage of the study.

It is illustrative for further Argument Delphi exercises to analyse more closely why this pacing technology was not mentioned. For that purpose, the author arranged a survey. The panellists of the biotechnology Argument Delphi were asked to participate in it. The aims of the PCR survey made in summer 1997 were to obtain information concerning:

- a) how important the method is now to the panellists;
- b) when the panellists firstly heard about the method and when they learned its basic technical features;
- c) from whom they heard or from which source they learned the basic features of the method;
- d) which types of difficulties panellists have had in using the method; and
- e) from whom they received help in the difficulties.

The basic idea of the survey was to explain how the Finnish developer community learned about the PCR and how much tacit or hidden knowledge about PCR the panellists had in 1989-1990.

From the twenty panellists who answered the question concerning their use of the method, six persons stated that they now use it often and two panellists said that they use sometimes. Twelve had never used it.

Taking into account that nobody mentioned the method during the Delphi interviews, it was interesting that five of the six panellists who now use the method extensively had already heard about it in 1989. Three of the six had even read a technical description of the method which was as extensive as the descriptions in the recent advanced basic books on biochemistry (2-3 pages). The other three of the six had read such a description in 1990-1991.

A panellist had heard about the method already before its publication in a lecture by Gary Mullis who has received the Nobel Prize based on the invention of PCR. Sources of the information were international congresses; one congress was Biotech 1986 in San Francisco (or Biotech 1985 in Washington DC) where Gary Mullis told about PCR. Two panellists mentioned lectures by Finnish experts from the Technical University of Helsinki and the University of Helsinki.

Besides the panellists who now extensively use the PCR, two other panellists knew the method in 1989 as extensive as the descriptions in the recent advanced basic books of the biochemistry. A now retired panellist heard about the method in a discussion of researchers in California.

Why was the PCR not mentioned in interviews, though many panellists knew it and some had even used it intensively? One explanation is that the interviews did not stress the techniques used. They were more focused on promising products. Another explanation is that the panellists did not see the importance of the method in 1989. Three panellists had heard about the method already before the interviews but had read the technical description of the method (2-3 pages) three to five years later.

The third and perhaps the most plausible explanation is that the information concerning PCR was so "hot" in 1989 that firms using it were not eager to tell about their present or planned applications of PCR. The firm of a panellist started development of new medicines based on PCR just after the panellist had heard about PCR in the lecture by Mullis, before the publication of PCR. A firm, the managing director of which was a panellist, is now a global marketer of the polymerase enzymes used in PCR.

A result of the survey which seems to support the third explanation was that few researchers have used other institutes as helpers in the technical problems of PCR. Most panellists who had used PCR answered "self-help" to the question concerning technical helpers. One mentioned TEKES and Sitra, one the University of Helsinki and a late beginner the University of Turku. It seems that there has been very little interaction between Finnish users of PCR at that time.

What kinds of general conclusions can we make based on the above study? The information policies of the "first best" experts seem really to matter concerning pacing technologies. Even if some "second best" experts have heard about important new generic ideas, they might be incapable of seeing their future importance. There are, however, often (typically?) some "champions" of the ideas e.g. in universities, who are capable and ready to communicate the technical points of the idea and its promises. In the biotechnology Argument Delphi, the champion was university professor who also worked in a new venture firm that actively used the PCR. It is essential that Delphi managers of the Argument Delphi include champions of this type on the panel.

## 6.4 Scenarios in the Argument Delphi Process: the Case of Environmentally Sound Materials

The fifth Japanese study and the first German study, which were accomplished at the same time as the study Kuusi (1994), included the following topic (Cuhls and Kuwahara 1994, 157):

Development of waste recycling technology, enabling the amount of city waste (i.e. that must be disposed of) to be reduced to half its current level.

The German panellists evaluated, that the topic was the second highest in importance among all 1146 topics evaluated (the index value 98). Also Japanese experts judged that the topic is very important (the index value 91). The degree of importance was evaluated with an index having the maximum value 100 and the minimum value 0, where the responses "high", "medium", "low" and "unnecessary" got respectively weights "4", "2", "1", and "0". The index value 98 means that nearly all experts considered that the topic is highly important.

If the common Japanese and German study would have had the Argument Delphi stage after the neo-classical Delphi stages, the topic would have been one very reasonable choice. The topic was actually a main focus of the author's Argument Delphi study concerning new materials (Kuusi 1994). Though it was not the only focus of the study, the whole study in a way provides a general framework for the discussion concerning the topic. This topic seems to be especially suitable for a discussion based on general scenarios. I will firstly present how the whole study process in Kuusi (1994) was accomplished. Then I will discuss how the specific topic was integrated with the discussion. Besides the demonstration of the proceeding from a "whole" picture to a particular issue, the description of the Argument Delphi process realized illustrates the general discussion of the Argument Delphi in Chapter 3.

### 6.4.1 Basic process features of the study

Among the three studies of Kuusi (1987, 1991, 1994) the study of 1994 was most clearly an Argument Delphi. The basic phases of the study were accomplished in 1991-1993. Delphi interviews were made in autumn 1991 and in spring 1992. The report of the first phase was mailed to the panellists in July 1992 and Delphi managers received the answers from all panellists before October 1992. The final Finnish report "Challenges of the New Materials" (in Finnish *Materiaalit murroksessa*) was published in Spring 1994 (Kuusi 1994).

The Delphi managers, the research board and the panellists of the study are presented in appendix 2. In *the first round* of the study, every panellist was interviewed by the Delphi managers personally or in groups of 2-3 persons. Most of the inter-

views were conducted by the author together with 1-3 other Delphi managers. Only a couple of interviews were made by the author alone. The idea was that the expertise of the other Delphi manager(s) was (were) as close as possible to the expertise of the interviewed panellist(s). The interviews lasted 3-5 hours.

The interviews focused on specific issue areas. Twelve basic issue areas of the new material technology and especially of polymer/composite technologies were defined before the interviews. The panellists commented first on those issues on which they were experts, based on the evaluation of the Delphi managers. After that they were asked to comment on other issues.

The experts were first asked to present promising Finnish products in the branches or application areas of carbon polymers or their composites. The application areas were the eight issue areas below:

1. Packages and films used in food production and delivery or in agriculture
2. Other paper and paper composite products
3. Other bulk material packages and bulk material products in construction (e.g. insulating materials for walls)
4. Other products in construction (e.g. building elements, tubes, tools)
5. Machines and vehicles
6. Electric devices
7. Textile, leather and furnishings products
8. Other uses of plastic or plastic composite products.

Beside considerations based on promising generic technologies, the list of application areas was motivated by the consumption of plastic products. In tons, packages were the most important use of plastic resins in Europe. In 1990, the share was 38%. The use in construction accounted for 20%. Vehicles, other traffic applications and different types of instruments and machines accounted for some 10%. The use in electric equipment was 6% and textile products, carpets, mats and furnishing products accounted for 7%. Other uses - household appliances, sport, health and hygiene and agriculture - accounted for 19% (Komppa et al. 1992).

The options and arguments discussed in the issue areas concerned situations in 2000 and 2010 with a few exceptions. The Delphi managers presented anonymous arguments of the other panellists already in the interview phase to interviewed panellists.

A study phase which linked it closely to the topic mentioned in the beginning of this section were two scenarios presented to the panellists. Each panellist was asked to evaluate their suggestions supposing that two scenarios had been realized. The discussion based on the scenarios was an important part in some interviews and sometimes even the dominating part. The scenarios concerned the recycling of materials and the use of energy:

### The recycling scenario

Society has a special interest in the recycling of materials in the following ways:

- Rates or taxes for waste management will be much higher than at present and the tariffs will be scaled according to the difficulty of processing the different types of waste.
- Distributors or producers are obliged to take back the packages or products at the end of their life cycle.
- Households are ready to sort their waste to different material groups.

### The energy use scenario

Society has a special interest in the use of energy in the following ways:

- Energy is saved and especially the use of fossil fuels producing greenhouse gases is reduced.
- The average real price of energy will double before 2000 and treble before 2010 based on taxes scaled according to the damage (e.g. carbon oxide, sulfur or nitrogen emission).
- The use of direct solar energy will obtain extensive development support as will the producers which considerably reduce their earlier use of energy.

Using the above scenarios as starting points the following issues were discussed in the first interview round of the study:

9. Production and use of energy
10. Pollution and waste management.

A part in the first round interviews concerned "the roots" of the discussed "technological bonsai tree". The experts were asked to evaluate how the qualities of the present plastics and their composites could be improved and how consumption of different plastics would develop. The experts were also asked if there are some recently found important polymers or polymer composites. The starting point of the discussion was a list of present properties and the realized consumption of different plastic resins and their composites. The idea was that promising generic technologies could be identified by asking the experts to argue for their evaluations. Based on market pull and technology push, the summary issues concerning the future role of carbon polymers, composites and other materials were discussed:

11. Production of plastics, other carbon polymers and their composites
12. Production of metal or ceramic products rival with carbon polymers.

A rather extensive report concerning the first stage was mailed to the panellists *in the second round*. The report included specified suggestions concerning 59 future relevant issues. The suggestions were mostly based on the presented arguments in the first round. The suggestions had five basic elements :

- a general description of the issue;
- a suggested point of view of the evaluation using a letter A, B, C or D, where (A) was the onlooker's or outsider's point of view; (B) was the future maker's point of view; (C) was failure minimization (maxmin) point of view; and (D) was the catching-hold-of-opportunities (maxmax) point of view;
- propositions or topics suggesting that something will be true of some future time (typically 2000 or 2010);
- simple yes/ no - type answers to the propositions or topics representing opinions of a median expert panellist (evaluations made by Delphi managers based on inter-views)
- anonymous factual arguments relevant to the issue.

The number of propositions or topics connected with an issue varied greatly: between one and fifty. Most of the issues explicitly or implicitly concerned new options based on the generalizations of polymer/ composite technologies and they took into account the environmental challenges described in the two scenarios.

The suggestions were divided into ten issue areas. The first three areas and the last area were general. The numbers refer to the order numbers of areas in the second round report:

1. Position of plastics among future materials
2. Suggestions concerning developer communities of materials
3. Waste management and the recycling of materials
10. Future options and dangers

Every panellist was asked to react at least to some of the suggestions made in these issue areas. Six areas were specific application areas of polymers/composites. The areas were:

4. Plastics which decompose in the environment
5. Future cellulose based materials
6. Textiles
7. Packages
8. Construction



## 9. Machines, vehicles and equipment.

One or two issue areas or branches were chosen as areas of special expertise for each panellist. Hence, the panellists were asked especially to comment on the suggestions concerning about 15 general issues or issues in the issue areas on average. This meant that they were asked to comment on average on about one fourth of the issues. Also, the other suggestions were mailed to them and they were asked to comment on them if they had time and relevant comments. The simplest comments were changes in yes/no answer proposals. Delphi managers asked, however, each panellist to give factual reasons for their evaluations even if they did not change a given evaluation. Panellists were also asked to comment on anonymous factual arguments connected with issues.

Besides the nominated special experts, typically 2-3 other experts made judgements and comments on the issues. Thus on average about 30 experts or two thirds of the panel commented on a general issue. Issues in the application areas were commented by on average of 15 experts. The distribution in the numbers of responses in different issue areas was, however, considerable.

In the *third round*, key panellists were asked to comment on specified parts of the preliminary versions of the final report.

The final report was based on discussions concerning interconnected issues typically commented by same panellists. There were five comparatively separate discussions in the final report:

- Key generic polymer technologies and general advantages and weaknesses of polymer materials and other materials in future
- Future of packages and films
- Future of materials in construction
- Future of materials in machines, vehicles and in electric devices
- Future of materials for use in solar energy.

### *General scenarios as sources of option reasonability*

Option reasonability was clearly the main focus of the study Kuusi (1994). In Chapter 3, I gave a necessary condition for the epistemic value of arguments concerning a generalization  $b$  if option reasonability is the main focus of a technology foresight study:

$I_b \times F_b \times V_b \times R_{bk}$  is reasonably over  $L_k$ , where  $k$  is any actor who is reasonably relevant for the realization of  $b$  from the point of view of the group of customers of the options-seeking study.

where  $I_b$  are the impacts of the technology generalization proposal,  $F_b$  its feasibility,  $V_b$  the validity of the generalization proposal,  $R_{bk}$  relevancy of the proposal to  $k$ .  $L_k$  is the minimum level of epistemic utility for a generalization proposal which  $k$  is ready to realize. Shortly: a technology generalization is option reasonable, if it reasonable from the point of view of any relevant stakeholder.

A discussion based on general scenarios like the recycling scenario above is especially suitable for an option-reasonability focused Argument Delphi study. *When the experts made suggestions based on the scenario, they actually produced options and arguments for a stakeholder who is especially interested in the realization of the topic mentioned in the beginning of this paragraph.*

The general discussion concerning future generalizations based on polymer technologies and their rivals and the more specific discussion based on two scenarios resulted in three future "technology generalization strategies", which are highly relevant for realization of the topic discussed. The final report of the study (Kuusi 1994) was largely based on discussion of these basic strategies of sustainable material policy in the future: dematerialization, durability and recycling strategies.

The strategies are based on a "technological program" or using a German word on a "Leitbild", which would probably not have been found if only experts of recycling technology would have made arguments about the issue: tailoring or customization of materials.

Customization means many different things in economic and scientific literature. What they all have in common is that a product is customized or tailor-made for a specific purpose much in the same way a tailor makes a garment fit a customer. The opposite of customization is mass production though an economic way of customization is mass customization. In mass customization great volumes of tailor-made products or varieties of a product are made e.g. using flexible manufacturing systems (Pine II, 1993). In addition to an exact fit there are other features characteristic of customization: high quality products, careful and detailed planning or design and features varying according to the user's needs.

There are two levels of tailoring of material products: customizing material and customizing of product made of that material. Customization of a traditional craftsman was focused on the last type of customization. As far as material is considered a tailor-made suit or a table made by a carpenter were in 1930's not very different than the mass products. Customizing material is still now rather irrelevant, when we think about metals used in a normal way. The strength of metallic object is proportional to the characteristic strength of the metal in question and the thickness of the object.

New technological advances in treating materials and especially new polymer and composite materials have made customization of material a focal problem. Many

have tried with disappointing results to replace a metallic part with a reinforced plastics part having a similar form. The strength of reinforced plastics - unlike that of metal - depends mainly on the direction of the stress. Resistance to strain is manifold on the direction of polymer chains or reinforcing fibers. Beside the strength it is also possible to tailor other qualities of polymer materials. The five-layered plastics used for vacuum-packed cold cuts is perfect for this particular purpose but would be totally unsuitable for packing bread.

The more detailed the customization, the harder it is to recycle the material using it in purposes differing from the original use. For example, if somebody melts multi-layered plastics its specific structure is damaged. Leather is an example of nature's detailed customization. As it overheats it loses its wonderful elasticity.

Based on the crucial role of tailoring, we can define three alternative strategies for a sustainable material policy. These strategies were discussed extensively in the study (Kuusi 1994, 84-166).

#### Dematerialization strategy

The strategy is based on tailor-made light and cheap materials, which are not, however, durable. Some experts considered that it is possible to produce films that meet the same basic functions as existing films, but with a thickness of one percent of that of present films by using many layers of different materials. According to the strategy, however, the recycling of the material and dematerialization will become increasingly contradictory. It is not usually economically feasible to repair goods made on the basis of dematerialization strategy. The most reasonable, sustainable way to handle composite polymer materials after use is combustion or composting. Metals in the composite materials can be recycled.

#### Durability strategy

The strategy is also based on tailor-made durable materials. They are typically heavier than the materials of the dematerialization strategy or if they are light - which is more and more possible based on polymer composite materials designed in details - they are expensive. That is why it is reasonable to repair products made of these materials or use old modules of these materials in new products. As in the dematerialization strategy, tailoring hinders recycling. The most reasonable sustainable way to handle the composite polymer materials, after a long use possibly in many different products, is combustion or use as filling material. Metals in the composite materials can be recycled.

### Recycling strategy

The potential for recycling is the starting point in the design of materials. This means that the potential for tailor-made designs is much more limited than in the dematerialization or durability strategies. The materials are heavier, not so durable or more expensive than in other strategies. On the other hand, simple materials can facilitate repair. In this strategy, there is little need for burning polymer materials, though recycling of polymer materials typically makes them weaker and a final burning or cracking is eventually needed.

Three strategies were discussed concerning packages of futures; future construction; materials in future vehicles, machines and electric equipment; and applications of biomaterials (for example paper).

Most experts in generalization or application organizations preferred the dematerialization strategy in all fields, though they were also ready to accept the recycling strategy in construction and in the recycling of paper. Most natural scientists also preferred the dematerialization strategy, but also accepted the recycling strategy in construction and in the recycling of paper. Especially in the field of packages, they potential for a durability strategy. Some experts of polymer composites also saw challenging opportunities for this strategy concerning vehicles, machines and electric equipment.

There was an expert representing the Finnish National Association for Nature Protection who heavily stressed the durability strategy. Other consumer stakeholders preferred the recycling strategy, which was also the preferred strategy of rivals representing mainly expertise in metals. The regulating experts of waste management preferred the recycling strategy thought they saw potential for the durability strategy in the fields of packages and construction.

There was, however, no systematic discussion during the study concerning the strategies. The above conclusions are based on the arguments given by the experts concerning different issues. It seems that this type of discussion would have been essential if the main focus of the Argument Delphi concerning the topic mentioned in the beginning of the paragraph would have been commitment reasonability.

## 7. CONCLUSIONS

This study has its "practical side" and its "theoretical side". I think that in the long run it is impossible to develop the practical side without good background theories. If we do not have good theories, we will confront the problem of the "Ptolemaic communication theory" discussed in Chapter 4. On the other hand, based on my rather extensive practical experience in the use of the Delphi method, I would like to warn newcomers to trust on nice theories too much. The learning processes of human beings and organizations are so complicated that it is very difficult to find any model or theory concerning their future-oriented activities that would work well in all connections.

I am, however, based on my analysis, ready to present some practical conclusions concerning development of the processes of national technology foresight studies in order to avoid bad results based on the information policies of experts and on the effects of group dynamics.

The anonymity, large groups of experts and standardized "proxy-arguments" have to some extent helped to avoid the combined problem of information policies and of the group dynamics in Delphi stages of national technology foresight processes. The studies have also taken into account some weaknesses of the classical Delphi studies realized e.g. by Brockhoff et al. (1975). The consensus of experts is no longer a special target of the studies. Most studies do not punish dissident views with a special requirement for further argumentation.

Though clear progress has happened especially in the Delphi stages of the foresight processes, I think that there are still possibilities to improve the validity and relevancy of the results of the foresight studies. The price of the focus on the use of "proxy arguments" has been considerable. My basic suggestions presented and discussed at the end of Chapter 4 were as follows:

- selection of working groups and Delphi panels taking into account the information policies and group influences in addition to the experts' expertise in relevant arguments;
- reduction of status differences between panellists;

- special Argument Delphi stage after "neo-classical" Delphi stages;
- asking for the best unbiased information of experts and the deliberate use of protagonists and antagonists especially in the Argument Delphi stage but also in other stages; and
- active roles for Delphi managers and synthesizers.

I also consider that my epistemic utility model, basic types of factual arguments and three types of reasonability might provide practical devices for analysing future oriented innovation processes both in foresight studies and in other connections.

What are theoretical, "long-term contributions" of the study? The basic theoretical starting point of this study is that the future-oriented behaviour of developers of technologies can be explained by their specific "languages". The general theory of consistency - which is the background of my discussion - makes a distinction between behavioural languages and other languages. There is a special (and often very unclear) relationship between behavioural languages and the languages which learning beings (e.g. single experts, firms or other organizations) use to understand or manipulate behaviour. We might also speak about unconscious behavioural languages related to "tacit knowledge" of experts and other more conscious languages.

The basic assumption of the general theory of consistency seems to be simple, but it still has wide implications concerning futures studies: it is possible to change behavioural languages of learning beings, but not the behavioural languages of not-learning beings. "The laws of nature" or invariances found by natural sciences are expressions of conscious languages - often written in the language of mathematics - which seem to *dominate* the behavioural languages of not-learning beings. The domination means that a natural scientist can anticipate how a not-learning being will behave or use its behavioural language. However, the natural scientist can never be sure that the languages really are in concordance. It is also possible to dominate learning beings if one finds transient invariances in their behaviour. Because of learning, the domination is, however, transient.

Innovations and technological development are based on generalizations of technological paradigms. A technological paradigm can be seen partly as a conscious language and partly as an unconscious behavioural language (tacit knowledge) of members of its developer community. Communication between members of a developer community and between different developer communities is based both on explicit and on tacit knowledge and also on information policies of experts and on influences of group dynamics. I think, that a great challenge of future studies concerning technology foresight is to understand more about technological paradigms and their interaction.

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## Appendix 1

### Basic Concepts and Postulates of the General Theory of Consistency (GTC)

#### Postulate 1. Learning and not-learning beings

a) It is possible to make true predictions based on two types of beings: *learning beings* and *not-learning beings*<sup>1</sup>. True predictions are not possible based only on not-learning beings<sup>2</sup>.

b) Both learning beings and not-learning beings have *behavioural languages*<sup>3</sup>. Learning beings can also have *other types of languages*<sup>4</sup>.

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<sup>1</sup> Like Eino Kaila (1940), I suggest that it is possible to constitute the universe into entities which behave invariantly or using the concepts of GTC: there are not-learning beings which do not change their criteria of sameness. Kaila suggested a research program based on his principle of invariance. From the point of view of the general theory of consistency, Kaila's program is a translation program: how to translate the criteria of sameness of not-learning beings into the languages of human learning beings? Invariant behaviour is the solid basis of predictions. If a learning being can realize which situations are similar from the point of view of a not-learning being, she can predict how the not-learning being will behave in those situations.

<sup>2</sup> Though it is possible to divide the universe into the not-learning parts like atoms, a dual description based on learning beings is needed. There is at least one being which necessarily needs a dual description as a learning being: the "Cartesian Ego": "I exist because I think" or "I exist because I learn and I am able to change my behaviour".

<sup>3</sup> The concept of behavioural language was not used in the first version of the theory. Information theory, semiotics and the general linguistics have used language based explanations of behavior. They were obvious starting points of the original GTC as the following citation shows (Kuusi 1974, 19-20): "The information theory is concentrated on the development of the best codes in a situation in which a sender of a message and a receiver of a message can make an agreement concerning the common code and the channel is known. A generalizing step which makes the situation more complicated, but which is a very commonly discussed situation in semiotics, is a situation in which the codes of the sender and the receiver differ. A situation which is especially complicated but important is a situation in which the sender and the receiver think that they have a common code, but actually their codes differ. This is not an exceptional situation: *according to the general theory of consistency every situation where it happens learning belongs to this type*". If in the above citation we use "language" in place of the code, the citation motivates the postulate 1b.

<sup>4</sup> Based on brain lesions, brain researchers have realised the existence of two basic types of memories: a memory for doing and a memory for nominating (Rose 1994, 136-138). In my conceptual framework they are based on a behavioral language and on another type of language. An example from Rose is riding a bicycle. You can learn to bicycle in your behavioral language. You might also learn the name "bicycle" in a language, that is only indirectly related to behavioral language. As a result of a brain lesion, a person may forget that the object with two wheels that she is capable of riding is a "bicycle".

c) The elementary elements of the languages are the *criteria of sameness (sems)*<sup>5</sup>. The criteria of sameness of a being's behavioural language define its behaviour<sup>6</sup>.

d) A learning being can change its criteria of sameness based on its learning capacities<sup>7</sup>. A not-learning being cannot change its criteria of sameness. A not-learning being always behaves *consistently* according to its *invariant* criteria of sameness. A learning being is able to behave *inconsistently* based on its changed behavioural language<sup>8</sup>.

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<sup>5</sup> An important background for my conception of language and the criteria of sameness in particular is the structural semantics of A.J.Greimas. In his book *Sémantique structurale* (Greimas 1966, in Finnish translation 1980, 28) Greimas started the analysis of the structure of a language by asking what does the expression "to perceive differences" exactly mean. His answer was:

a) To perceive differences means: to perceive at least two similar object terms

b) To perceive differences means: to realize the relationship between terms and connect them in a way.

Hence from a) and b):

c) In order that two object terms can be conceived as a totality, they have to have something in common (the problem of similarity).

d) In order to make a distinction between two object terms they have to be not-similar in some sense.

Greimas called the totality of two object terms A and B a *semantic dimension*. Greimas considered that A and B belong to an object language and they are achieved through an act of perception. The perceived differences as such are not, however, the distinctions which languages use. It is possible to articulate the perceived differences based on their properties or *semic dimensions*. Roman Jakobson remarked that the phonologic description of the classic Arab language requires 26 phonemes. This produces a program of 325 oppositions. It is, however, possible to describe the 31 phonemes of a North-Palestinian Arab dialect using only nine *sems*.

Despite the presence of a semic dimension (s contra not-s), the semic dimension is not present in some connections (using my terms: it is not *relevant* in some connections). Greimas uses a notation - s. There are four semic possibilities in a connection

s	(the presence of s)
not-s	(the presence of not-s)
- s	(the lack of s and not-s)
s + not-s	( the presence of s or not s)

In the last case, the presence of the semic dimension is realized, but we do not know whether s or not-s is present ( a complex sem compare *knowledge interest* below). The concept of the semic dimension is the key concept of Greimas' structural semantics, on which for example his famous semiotic square is based. In a language a semic dimension is the level on which basic distinctions are made concerning the similarity of objects. Based on that fact, let us call the above four basic semic possibilities *basic criteria of sameness* in a language. This Greimasian idea has been an important starting point for my general theory of consistency. I have extended the Greimasian concepts to deal with the problems of learning and prediction. You can find Greimasian counterparts of my concepts in parentheses and in black letters.

<sup>6</sup> If a being has not changed its relevant criteria of sameness, that being behaves in similar ways in similar situations *based on its own criteria of sameness*. From the perspective of the criteria of sameness of another being, it may behave in different ways in similar situations.

<sup>7</sup> According to Rose (1994,155): "The learning is a reaction of an animal to a new situation. The reaction changes its behaviour reliably so that the animal behaves more properly than before, if it meets the situation again." A possible interpretation of the learning concept of the GTC is that it tries to generalize this idea of learning to concern beside animals all learning beings.

<sup>8</sup> The inconsistency is based on one's own criteria of the sameness of a being. From the perspective of another being, it may behave consistently.

### Corollary 1 **The weak principle of invariance**

It is possible to find practically *certified not-learning beings*.<sup>9</sup> A being is a certified not-learning being if it is possible to translate its criteria of sameness (*sems*) into the language of a second being so that the second being can predict the future behaviour of the first being without further information concerning criteria of sameness of the first being<sup>10</sup>.

### Assumption 1 **Private language assumption**

The criteria of sameness of a being are based on *basic differences (distinctive features)* which the being can take into account<sup>11</sup>.

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<sup>9</sup> The corollary follows directly from the postulate 1 a. The corollary does not require that an actor can predict all future behavior of a certified not-learning. The point is that something is considered to remain constant or invariant in predictions e.g. in physics. As Kaila has remarked this principle of invariance is necessary for measurements. Kaila considered that he was able to show that (Kaila 1979, 159) "the theory of temperature was in fact based on the presupposition preceding all measurements that a certain thermal quantity is constant, and ... the development of the concepts of thermometric measures becomes intelligible only in view of this principle of invariance". Kaila's point is that it is of course in principle possible to give up the presupposition, but not in practice. What we know, however, is only the predictive dominance of our language concerning the language of the measured not-learning being.

<sup>10</sup> The theoretical problem of whether there is a universal language in which all beings can be described as certified not-learning beings has not been solved. We might call the search for such a language *the strong principle of invariance*. The principle of invariance discussed by Kaila (1940) seems to be this strong principle. In the first version of the GTC, I discussed this topic (Kuusi 1974, 102): "It is somewhat interesting to suppose a being which has extremely wide capacity limits to take the criteria of sameness of all beings simultaneously into account (compare the postulate 2 below). This being could predict exactly - supposing that learning beings have in principle a dual description as not-learning beings - how the beings behave in different situations. It is possible to call two situations *objectively similar* if this type of being does not perceive a distinction between them".

<sup>11</sup> It seems that people and probably many other species have a capacity to perceive distinctions and remember them. This is an evident feature of the eidetic memory of children and some adults. An eidetic memory is, however, not very functional in comparison with a common language of many learning beings (compare Rose 1994, 117-122). Assumption 1 is very simplifying because the learning beings usually (and people practically always) are born in communities with well-developed languages. A new speaker of a natural language has mainly to accept the concepts of the language as given. A capacity of a natural language to discern differences between *relevant* entities is a cultural capacity. A single speaker uses this capacity for the development and communication of his or her criteria of sameness. The speaker may take into account the cultural distinctions made in the language without any direct experience concerning them. A problem is, however, that the speakers do not use the concepts in similar ways: though they use common concepts they often communicate different criteria of sameness. In behavioural languages customs and routines have roles similar to concepts in natural languages. Though the assumption made is not very useful for the description of how people learn existing languages, it is very useful in analysis of the changes in languages e.g. based on perceived inconsistencies or contradictions (see postulate 3d). *Unlearning is based on perceived differences and inconsistencies*. When a person develops his or her behavioural language, the unlearning of earlier concepts and routines is a key element in the learning process.

## Postulate 2 A description of the criteria of sameness based on the private language assumption

The criteria of sameness can be stated as follows:

- a) A basic difference which a being can take into account defines a *basic dimension (semantic dimension)* describing a difference between two *basic entities (object terms)*.
- b) The criteria of sameness of a being give meanings to basic dimensions. The meanings are based on the *interests* of the being. The criteria of sameness (*sems*) translate basic dimensions (*semantic dimensions*) into *binary (semic dimensions)* or *joint dimensions*. Different meanings of entities of a dimension are the different *values (semic possibilities)* of the dimension. A binary dimension includes a "contradiction" between two different values<sup>12</sup>. A joint dimension includes at least three different values and it is based on combined binary dimensions. A joined dimension is based on a transitive relation between three or more values. It is a *preference relation* or a *probability relation*.<sup>13</sup>

## Postulate 3 Capacity limits or capacities of a being

The capacity limits or capacities include two types of elements: the *capacity limits of taking into account* and the *capacity limits for making true (or realize)*. Within the capacity limits of the first type are all the basic differences (*semantic dimensions*) or perceptible criteria of sameness of other beings which a being is able to take into account<sup>14</sup>. Within the capacity limits of the second type are capacities for realizing values in different dimensions (and so for hindering the realization of values which are in contradiction with them)<sup>15</sup>.

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<sup>12</sup> In the first version of the theory, a clear distinction between basic dimension and binary dimension was not made. The definition of the binary dimension was dynamic: "A binary dimension (A,B) includes two contradictory criteria of sameness. The dimension will exist as long as a contradiction between A and B remains" (Kuusi 1974, 79). Compare a problem solving situation in which a person tries to realize A instead of B. I will discuss the interpretation more closely in connection with interests.

<sup>13</sup> For example in a joined dimension (A,B,C) A is more probable than B which is more probable than C which implies that A is more probable than C, compare Kuusi (1974), 101

<sup>14</sup> Besides the capacities of a being to perceive differences, its capacities to take into account depend on its languages, which take into account distinctions that the being cannot (at least directly) perceive. Important features of the capacity for taking into account (and the capacity of a language) are the capacities to remember and synthesize the distinctions made. They are basic elements of learning based on interests. A learning being might have the wrong expectations concerning its capacity limits (compare postulate 4d).

<sup>15</sup> In the first version, I gave an overly narrow definition of the capacity limits. I defined them as those changes which a being can realize in the instrumental dimensions in a situation (Kuusi 1974,76). I think that it is also reasonable to include the information processing capacities within the capacity limits.



#### Postulate 4 **Interests of a being**

a) An interest is a *totality of relevant dimensions*.<sup>16</sup>

b) An interest has a *target dimension*<sup>17</sup> and relevant *instrumental dimensions* related to the target in a situation defined by relevant *situation dimensions*<sup>18</sup>. A being tries to achieve a proper value in the target dimension. The proper value is based on proper values in instrumental and situation dimensions<sup>19</sup>. It is possible to divide a process of an achievement of a proper value in the target dimension in different sub-tasks or *sub-interests*<sup>20</sup>. It is possible to delegate sub-interests to other beings.

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<sup>16</sup> "...in the framework of the general theory of consistency, it is not possible to analyse targets, means and actions separately. In this sense, the concept of interest in the GTC has common features with the practical syllogism discussed extensively in the philosophical literature " (Kuusi 1974, 72). An important idea in the first version of the theory was that interests and especially the most urgent interest (the *antagonistic* interest) determine *relevant* dimensions in a situation. 'Telling the whole truth' in a situation depends on relevant dimensions. Kuusi (1974,65) illustrated this 'total truth' problem with the following example. Let us suppose that a country A is at war with another country. Let us suppose that a newspaper in A makes war reports. Let us suppose that the target dimension of an (antagonistic) interest of all citizens in A is to defeat the enemy without mercy. A relevant dimension from the point of view of this interest is the number of destroyed enemies. "The sufferings of enemies" is not a relevant dimension. "The whole truth" does not require reports on it. If the interest of most citizens is, apart from victory, to minimize the sufferings of enemies, the whole truth requires the reporting of the sufferings of enemies.

<sup>17</sup> In the first version, the target dimension was defined as a unity of contradictory elements or as a dimension which articulates an interest defining contradiction (Kuusi 1974, 68) The idea was that an interest-related problem is not solved and a contradiction prevails before only one value obtains the probability 1 and others 0 in a case of a knowledge interest (compare e.g. Kuusi 1974,81) or the preferred value in the dimension is achieved in a case of a welfare interest.

<sup>18</sup> One way to define the difference between learning and not-learning beings is to assume that the "interests" of not-learning beings are based only on situation dimensions. A not-learning cannot change its behaviour (or behavioural language) because it has no instruments (including "knowledge instruments" based on memories) to change its behaviour. The changes in its behaviour are determined reactions to changes in the situation.

<sup>19</sup> In an action theory of learning beings based on the idea of interest, Kuusi and Keloharju (1984) pointed to four basic "strategies" for the changes sought in a target dimension. They connected instrumental dimensions directly to the capacities of actors (to their *resources*). The connection between resources and situation dimensions was indirect. A first strategy is to accept the situation dimensions or "barriers" as they are and overcome the barriers using the resources ("direct action module"). A second strategy is "wait and see" if the situation will become better so that the target is possible to achieve with (less) resources ("a passive change of a condition module"). A third basic strategy is to use resources for the elimination of barriers ("an active changing of a condition module"). A fourth basic strategy is to use resources to produce more resources ("the widening of capacity limits module").

<sup>20</sup> Kuusi and Keloharju (1984) described the active changing of a condition module and the widening of capacity limits module as subinterests.

c) A being has a *level of achievement* concerning any interest. There are two basic types of interests. In the case of a *knowledge interest (complex sem)* the level of achievement is defined by the probability values<sup>21</sup> in the target dimension. In the case of a *welfare interest* the level of achievement is defined by the preference values in the target dimension.

d) The interest related actions are based on *basic expectations*:<sup>22</sup> if and only if a being behaves in similar ways (according to values in relevant instrumental dimensions) in similar situations (according to values in relevant situation dimensions) are the results similar (according to values in the target dimensions of its interests).<sup>23</sup> If a being has a proper memory, it can change its behaviour based on its *perceived contradictions* concerning the realization of basic expectations<sup>24</sup>.

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<sup>21</sup> The problem of a knowledge interest is to decide between different values in the target dimension. Ideally in any situation only one value can prevail in the target dimension if the knowledge interest tries to decide the criterion of sameness of a not-learning being in that dimension. Hintikka (e.g. 1973, 224-225) defined the *surface information* for all the sentences of some given applied first order language. He used as measures of information probability-like weights that are assigned to the sentences. A probability measure of a sentence  $F$   $p(F)$  was thought to be a degree of belief (of some sort) that one can rationally assign (a priori) to any sentence of a language. Like Hintikka we may consider different values in the target dimension  $V_i$  of a knowledge interest as "inconsumerable sentences" (criteria of sameness) with different degrees of belief  $p(V_i)$ . A knowledge interest tries to specify situation conditions (compare *constituents* in the framework of Hintikka) minimizing the insecurity concerning which value  $V_i$  prevails. Ideally the probability of one value  $V_i$  is 1 and others 0. Beside the invariant criteria of sameness of not-learning beings, the successes in knowledge interests depend on the welfare interests of learning beings (compare Kuusi 1974, 87-94).

<sup>22</sup> The concept "basic expectation" was not used in the first version of the general theory of consistency. Its content is, however, essentially the same as "the basic idea of the theory" (Kuusi 1974, 4): *If the same operation made to the same object produces different results some being has to change its criteria of sameness.*

<sup>23</sup> Let us suppose that (behavioural pattern 1, situation 1, result 1) and (pattern 2, situation 2, result 2) refer to same basic expectation. We may assume that based on its criteria of sameness, the being has a group A of similar behavioural patterns (similar values in relevant instrumental dimensions) and a group B of similar situations and a group C of similar results. From the perspective of produced result 1 and 2 belonging to the similarity group C, the being expects no difference between the behavioural patterns 1 and 2 belonging to A if situations 1 and 2, where the behavioural patterns are used, belong to B. The similarity supposed between patterns 1 and 2; situations 1 and 2 or results 1 and 2 does not require that the being could not discern the difference between 1 and 2. The similarity or the sameness of 1 and 2 is the basic expectation specific.

<sup>24</sup> A necessary condition for a learning being is that it has a memory.

e) A change in the criteria of sameness (or learning ) may also be based on the reaching or not-reaching of the achievement level resulting in a higher or a lower achievement level. If a being has permanently achieved the highest achievement level in an interest the interest is permanently *realized* and the learning based on the interest stops.<sup>25</sup>

#### Postulate 5 **The genuine learning being or the actor**

Let us assume that a first being had in the past predicted rightly the behaviour of a second being in a situation. The second being is *the genuine learning being or actor from the point of view of the first being* if the second being has capacities and if it is ready to change its criterion of sameness so that the first being is, after the change, not able to predict its behaviour in the situation without further information concerning its criteria of sameness.<sup>26</sup>

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<sup>25</sup> In the first version, I call these changes different types of negations. The reaching of the achievement level of an interest means that a basic expectation is realized. Only some changes in the instrumental dimensions belong to the capacity limits of a being. As in the realization of a plan the (learning) being may await the proper situation for the realization of the interest. It can also try to delegate sub-plans or sub-interests to other beings.

<sup>26</sup> Alan Turing presented "Turing's test" in 1950s: Let us suppose that you use a telex to communicate with another telex in another room. If you cannot discern if you are communicating with another person or with a machine the machine has some artificial intelligence (compare Rose 1994, 97). An interpretation of the Turing test is that the intelligent machine can use your language intelligently enough. I consider that a stronger sufficient condition is needed for a genuine learning being. Let us suppose that in the Turing test you have a paper before you. If you cannot manipulate the machine to answer your message as is written on your paper, the machine could be a genuine learning being. It is, however, only a candidate: the unpredictability may be based on its poorly known past invariant criteria of sameness. In more general terms: a practical definition of a genuine learning being is its ability based on its learning to nullify in an unpredictable way a prediction with a change in its behaviour. People and perhaps some intelligent animals are examples of this type of genuine learning beings as are their organizations. In the future, an important group of learning beings are probably neural computers, the behaviour of which is ruled by programmed interests and which can make action decisions independently. Even now, it may be plausible to interpret the computers and even written documents to be organic parts of learning organizations.

## Corollary 2 Necessary conditions for an actor

Let us suppose that a first being had in the past correctly predicted the behaviour of a second being in a situation. There are three necessary conditions for the second being to be a genuine learning being or an actor from the point of view of the first being

- a) The second being has not-realized interests.<sup>27</sup>
- b) The second being has an active memory as a store of its learning experiences.<sup>28</sup>
- c) The second being has capacities to change its behaviour as the result of its learning.<sup>29</sup>

## Postulate 6 The essence or genuine interests of an actor

a) The essence of a genuine learning being or an actor is defined by target dimensions of its *genuine interests*.<sup>30</sup> No experience can change the (real or true) preference order in the target dimension of a genuine interest. In other words, the order of values in the target dimension of an actor's genuine interest is invariant<sup>31</sup>. If the order changes the actor is not the same actor as before (for example an organism dies ).

b) A learning being does not typically know her genuine interests, but she learns to know them through *her experiences of repentance* if she has a feasible and active memory.<sup>32</sup>

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<sup>27</sup> A robot, which is programmed to do certain determined tasks, is a being, that cannot change its criteria of sameness. It is an example of a not genuine learning being, that has a memory and action capacities but does not have interests. A robot can change its criteria of sameness only if somebody changes its software to promote her interests.

<sup>28</sup> A simple thermostat is a being, with such a simple memory that you can easily predict its behaviour. This is the reason to classify it as a not-learning being, though it has an "interest" to keep the temperature within certain limits and it has a capacity to start an action, that contributes to the fulfilment of the target.

<sup>29</sup> According to de Jouvenel, for a given person the future is divided into dominating and masterable parts (de Jouvenel 1967,52). A disabled person cannot save himself from a fire, because this is not within his capacity limits. In this "dominating future" the disabled behaves like a not-learning being. The masterable future is what a person can change according to his or her interests. De Jouvenel stressed an important point: "in human affairs the future is often dominating as far as I am concerned, but is masterable by a more powerful agent, an agent from a different level" (for example a state, the author's addition)

<sup>30</sup> There are two possible metaphysical explanations for the invariance of the criteria of sameness of a not-learning being. The first explanation is that the not-learning being is indifferent to the results of its action (it has no genuine targets). The other metaphysical explanation is that even in the case in which the expectations of the not-learning being are not met (it has genuine targets and it can compare its expectations with the results of its behaviour), it cannot change its behavioural language.

<sup>31</sup> The genuine interests of a learning being in a way resemble the permanently invariant criteria of sameness of not-learning beings.

<sup>32</sup> If many actors, for example human beings, have the same or similar interests, it is possible that an expert, for example a physician, knows some genuine interests of a person better than that person himself, though only that person (or some other learning being) has a direct access to his experiences of repentance or frustration. The physician can take into account the experiences of similar actors.

### Postulate 7 **Capability limits of an actor**

The actions which do not produce experiences of repentance belong to the *capability limits* of a being.<sup>33</sup> The learning and behaving of an actor is undetermined or path-dependent because there may be many different actions in a situation which belong to the capability limits of the actor and the capability limits change according to specific learning experiences resulting from selected actions.

### **A summary conclusion**

The general theory of consistency gives a metaphysical justification for different scenarios of the future. *In summary, futures research based on this paradigm is research on the capacity limits, capability limits and interests of actors and the study of possible and desired futures based on this type of knowledge. In the case of a not-learning being, the activity recommended by the paradigm is seeking invariant criteria of sameness.*

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<sup>33</sup> Beside the perceiving of genuine interests the capability limits depend on true basic expectations including true basic expectations concerning capacity limits. A being can have false basic expectations concerning its capability limits.

## Appendix 2

### **Finnish Material Communities and the Experts in the Study concerning the Future Use of Polymer Materials**

#### *1. Finnish material communities*

In the study of Kuusi (1994), a material community was defined to be a network of persons, firms, research institutes and other institutes. Its actions and decisions were defined to be decisive for the development of some materials and for the selection of those materials in different applications. At present, one can hardly identify one national or international developer community of material technology. It is at present reasonable to speak rather separate developer communities (and technological paradigms) concerning metallic materials, ceramic materials, wood & paper materials and plastic materials, though composites combining all materials have continuously become more important.

The separateness hypothesis was tested in the second round of the Delphi study Kuusi (1994). All panellists accepted the following suggestion concerning Finnish material communities:

At present the developers and producers of plastic products are separated from developers and producers of metallic materials, ceramic materials and wood & paper materials.

Though the panellists' evaluations were based on a comparison with Finland and other OECD countries, it is reasonable to assume, that separateness is not only a Finnish problem. With one exception the panellists rejected even the following suggestion:

At present, the developers and producers of plastics products have close connections with the producers of paper and board .

The deviant panellist was a special expert on packages. The relative separateness of material communities will probably continue in the near future, but in the long run the developer communities may integrate as was also anticipated by the panellists. In the present situation it is reasonable to call developers of different materials as rival experts.

An important feature of the plastic developer community in Finland (and world-wide) is its newness in comparison with long traditions of metallic, ceramic or paper materials. The production of plastics products started in Finland in 1921 with a company (Servis Co) producing buttons and buckles from milk casein. It took over ten years

before a next Finnish user of plastics started. Just before World War II there were about ten firms in Finland making plastic products.

After the war, the Finnish plastics industry grew rapidly. The number of firms producing plastics products was estimated to be 760 at the end of 1990 (Neste... 1992). At the time of two first Delphi rounds of the study one multinational plastics producing company (Neste Co.) had a key position in the Finnish plastics community. It was the only firm in Finland producing plastic resins.

## *2. Experts and their types of expertise*

The study had six Delphi managers: Osmo Kuusi (VATT, the Government Institute for Economic Research); Petteri Sivula (VATT); Veikko Komppa (VTT -Technical Research Centre of Finland - Chemistry); Arto Mölsä (VTT Chemistry); Irina Aho-Mantila (VTT Metal); Heikki Kukko (VTT Construction). Komppa, who was also a panellist, was the professor and the director of the VTT Chemistry research laboratory, Aho-Mantila and Kukko were senior researchers and doctors, Sivula and Mölsä were junior researchers.

The study also had an advisor group which together with the Delphi managers played a key role in the selection of panellists. It included leading experts of material technology at VTT: Prof. Tor-Magnus Enari (VTT Biotechnology), Prof. Simo-Pekka Hannula (VTT Metal), Prof. Heikki Kleemola (VTT Metal), Prof. Veikko Komppa (VTT Chemistry), Liisa Rautiainen (VTT Construction) and research manager Antti Romppanen (VATT). Hannula, Kleemola, Komppa and Rautiainen were also panellists.

The 45 Delphi panellists are below classified into the basic stakeholder groups discussed in Chapter 5. I call rivals all researchers or realizing experts specializing in materials other than plastics, their composites or wood & paper. Also, those members of the wood & paper community who did not use plastics composites were classified as rivals. An important new category in the list comprises experts in institutions that link university research and realizing firms. There are only 40 items in the list of panellists because 5 panellists gave answers together with some other panellists. The panellists are presented in the order of interviews. I will later use the rank order numbers for the identification of panellists.

1. Natural scientist, synthesizer, link institution (professor VTT -Technical Research Centre of Finland - Construction)
2. Natural scientist, link institution (professor, VTT Chemistry, specializing in plastics)
3. Natural scientist, rival (professor, VTT Metal)
4. Natural scientist, rival (professor, VTT Metal)
5. Administrator, application organization (product manager in a firm using plastic composites)
6. Natural scientist, basic research (associate professor at TKK -Technical University of Helsinki - specializing in advanced polymer composites)
7. Natural scientist, link institution (professor in KCL - Central Laboratories of Finnish Forest Industry - specialized in polymers of wood and textiles)

8. Administrator, synthesizer, application & generalization organization (managing director and a researcher at the Finnish Plastics Association)
9. Administrator, application organization (project manager in a firm making polymer furniture and walls)
10. Natural scientist, generalization organization (managing director of a small firm specializing in advanced polymer composites)
11. Administrator, generalization organization (research director of a large firm which makes plastics)
12. Natural scientist, generalization organization (director of a firm specialized in the use of advanced plastic composites)
13. Natural scientist, generalization organization (research director in a firm using small plastic components, e.g. in electric equipment)
14. Natural scientist, regulator (senior researcher of TEKES, Technical Development Centre of Finland, specializing in the funding of applications in material technology)
15. Natural scientist, generalization organization (development manager in a firm making products based on plastic composites)
16. Administrator, application organization (research director in a firm making mostly ceramic products for construction, but also applications based on polymers)
17. Natural scientist, link institution (senior researcher, VTT Pyrotechnology)
18. Natural scientist, basic research, generalizing organization (professor of TTKK - Tampere University of Technology - specialized in biodegradable polymers)
19. Natural scientist, rival (associate professor of TTKK specializing in advanced ceramics)
20. Natural scientist, generalization organization (research director in a firm specialized in advanced polymers)
21. Natural scientist, basic research (professor in polymer technology of TKK)
22. Consumer stakeholder (a woman, who has written a critical book about plastics for the Finnish Nature Protection Association)
23. Natural scientist, regulator (senior researcher specializing in the financing of construction in TEKES)
24. Natural scientist, generalization organization (managing director of a firm making applications based on advanced polymer composites for aircraft)
25. Natural scientist, link institution (researcher at KCL specialized in the recycling of paper)
26. Administrator, rival (managing director of a firm specializing in recycled paper as an insulating material in construction, very critical concerning the use of plastics)
27. Synthesizer, consumer stakeholder (eco-consult used by the Finnish Nature Protection Association)
28. Synthesizer, consumer stakeholder (eco-consult used by the Finnish Nature Protection Association)
29. Administrator, regulator (civil servant at the Ministry of Environment specialized in waste management)
30. Natural scientists, link institution (researchers at KCL, specializing in the package technology)
31. Natural scientist, application organization (research manager in a firm specialized in the production of waterproof packages)
32. Natural scientist, generalization organization (research director and researcher in a large firm specializing in plastics pipes)
33. Administrator, regulator (civil servant in the Ministry of Environment specialized in waste management)
34. Administrator, regulator (civil servant in the Ministry of Foreign Affairs specialist in waste management)
35. Natural scientists, application organization (research director and researchers in a small firm specializing in the recycling of cars)
36. Natural scientist, application organization (research director in a firm making mostly ceramic products for construction, but also applications based on polymers)
37. Natural scientist, basic research (docent at the University of Helsinki, specialized in the basic physics of materials)
38. Natural scientist, generalization organization (research director of a large paper producing firm)
39. Behavioural scientist, consumer stakeholder (researcher in the Consumer Research Institute making study concerning the consumption of plastics)
40. Behavioural scientist, rival (researcher in VATT - the Government Institute for Economic Research - specializing in the world markets of metals)

The ten polymer scientist panellists (or small groups of panellists) had various special types of expertise. Researchers 2, 6, 18, 21 were technical specialists in the use of plastics or plastic composites. Panellist 1 was a specialist in materials in construction,



7 was a scientific expert especially in cellulose fibers, 17 in pyrotechnology, 25 in recycling of paper, 30 in packaging technology and 37 in basic physics of materials.

Sixteen panellists (or small groups of panellists) are classified as realizing experts. It is possible to divide this group in three subgroups. The realizing experts 8, 11 and 32 were "plastic generalists". They, or at least their institutes or firms were prominent decision makers in the Finnish material community being mass producers or users of plastic resins or general promoters of the use of plastic resin materials. The realizing panellists 10, 12, 15, 20 and 24, were technical specialists in the use of plastics or plastics composites. The third subgroup of the realizing experts was rather heterogeneous. They - 5, 9, 13, 16, 31, 35, 36 and 38 - represented different types of application firms using plastics and also other materials.

Five panellists were classified as rivals. Except for 26, all were experts specialized in metals or in ceramic materials. The class of regulating experts included two representatives of funding (TEKES) and three civil servants specializing in waste management. Four panellists were classified as "consumer specialists". Except for 30 they have close links with the Finnish Association for Nature Protection.

Another way to look at the roles of panellists is to look at their organizations. Four panellists were university researchers. Eight panellists worked in public research or development institutes (TEKES, VTT, Government Institute for Economic Research). Nine panellists worked in the multi-client research institutes of industry, in an association of industrial firms or in a multi-client consulting firm (KCL, Package Research Group of Finnish Industry, Finnish Plastics Industry Association, Advanced Environment Management - the consulting firm). Fifteen panellists were research managers or researchers of firms. Three panellist were experts in the public regulation of waste management. Five panellists were selected to the panel as representatives of environmental organizations though two of the them were also managing directors of small "alternative firms" and three were researchers focused on consumer and environmental issues.

A way to classify the experts is to try to formulate indicators of their expertise based on the comments produced and on the background of experts. I present this classification as an illustration of a way which can be used to operationalise the basic classification into scientists, decision makers and synthesizers.

*Synthetic expertise.* Synthesizers are experts with expertise or well argued opinions on many different uses of polymers. The synthetic expertise can be evaluated by a simple indicator. This crude and not very valid indicator is the average number of issues commented by the experts in the first round of the study. Because the comments were the result of a rather unstructured interaction process between the Delphi managers and the interviewee, the expectations of the Delphi managers concerning the "synthetic abilities" of the interviewee had an impact on the number of discussed areas. The experts made, however, final decisions to comment or not to comment on an issue.

Mass producers or users of plastics or general promoters of the use of plastic resin materials obtained the highest average score, 7,0. In the group of scientists researching carbon polymers or their composites, the average score was 6,3. The average score of public administrators of recycling of materials was also 6,3 and consumer or environmental organization experts in future demands for carbon polymers or their composites obtained the next highest score, 6,0. In the group of general experts in material sciences the average number of discussed areas was 5,3. Other groups obtained the following average scores: specialists in qualities of rival materials of carbon polymers 5,2; experts in recycling technology 4,5 and finally specialists in applications of advanced carbon polymers and their composites 3,0 .

*Core ("paradigmatic") scientific expertise.* The evaluation of the core scientific expertise in polymers (and especially plastics) and in their composites is based on the positions of experts in the developer community. Experts researching, producing or applying new plastics resins or carbon composites received a score A. Other experts who had studied or used plastics or their composites received a score B. Others received a score C.

*Rival scientific expertise.* The evaluation of the rival scientific expertise in other materials is also based on the positions of experts in the developer community. Experts researching, producing or applying other materials received a score A. Others received a score C.

*Core decision making expertise.* The evaluation of the core decision making expertise in polymers (and especially plastics) and in their composites is based on the capacities of experts to make production decisions or to regulate production directly by for example standards or indirectly by consumption decisions. All representatives of realization organizations, which were managing directors or planning directors of firms received a score A. Experts representing public regulating organizations or consumer viewpoint received a score B. Others received a score C.

*Critical decision making expertise.* The evaluation of the critical decision making expertise is based on the capacities of experts to make production decisions which can be based either on carbon polymers (+ their composites) or on other rival materials. The representatives of application organizations, which have to compare different materials, received a score A. Experts representing public regulating organizations or consumer viewpoint received a score B. Others received a score C.

## Appendix 3

### The Motivation of the "Ideal" Technological Paradigm of New Biotechnology in 1989-1990

The concepts of the paradigm of the new biotechnology are mostly developed based on invariances found in three interconnected sciences (Moses and Moses 1995):

- Biochemistry, which addresses the chemical structure and behaviour of all types of living beings
- Genetics, the study of inheritance and the relationships between individuals and populations;
- Microbiology, a field closely integrated with both biochemistry and genetics, which explores and manipulates microbes of all sorts

The basic scientific concepts of these sciences are given in many introductory books on these sciences. A short introduction of concepts of these sciences were also given (in Finnish) in Kuusi (1991).

#### 1. Recombinant DNA technology

The evident key generic technology of the past few decades of biotechnology has been the development of *techniques to allow the transfer of genetic information from one specie to another specie (K1)*. In successful applications this is done in such a way that the protein(s) specified by the transferred gene(s) can be made (expressed) in the new host.

Recombinant DNA technology is part of molecular biology, a name often used for the interface between biochemistry and genetics. The basic techniques of this technology are *methods that make possible to get a cell to accept a strange string of DNA, which codifies the production of a protein (K1)*. The "acceptation" means, that the cell begins to produce the protein (closely e.g. Moses and Moses 1995, 32-37).

The first techniques concerned the transfer of a string of DNA to bacteria, which rather easily accept DNA material. Manipulating the genes of plants and animals presents more technical problems than those in bacteria. Not only is their genetic organization very much more complex, but the cells are part of a large structure, the body of the animal or plant.

Basic techniques provide several ways of inserting foreign DNA into isolated cells of animals or plants (Moses and Moses 1995, 38):

The first realized target concerned bacteria. A prerequisite of effective genetic material is the replication of transferred genetic material as the cell grows and divides. The replication will occur only if the DNA contains a sequence that is recognized by the cell as an origin of replication (Wilson and Walker 1996 p.133). Most DNA samples do not contain such sequences and therefore the transferred DNA has to be attached to a carrier or vector DNA that contains an origin of replication. The first carrier technique involved the use of plasmids of bacteria. A plasmid is a relatively small, circular extrachromosomal molecule, which contain an origin of the replication.

Now many techniques are also available to accomplish the transfer to isolated cells of animals and plants (Moses and Moses 1995, 38):

1) *In certain chemical environments, animal cells will take up DNA from environment, just as bacteria will. The process can be helped by applying an electric current (K1a) which helps to enlarge the natural pores in the membrane surrounding the cells, a method called electroporation.*

2) *Because of their large size, it is possible by microinjection to inject a DNA-solution directly into animal cells (K1b).*

3) *It is possible to incorporate the DNA into certain viruses which are then allowed to infect the animal cells (K1c).*

4) *Using some viruses, it is sometimes possible to persuade cells from different animals to fuse together, resulting in cell hybrids containing the DNA from both (K1d).*

5) *In the technique of particle acceleration, the DNA to be transferred is coated onto minute gold particles which are fired at target cells (K1e) in an electric discharge apparatus.*

The potential generalizations of recombinant DNA technology concern the techniques of the effective transfer of DNA to different types of cells applying an electric current which helps to enlarge the natural pores in the membrane surrounding the cells, a method called electroporation.

## 2. Cloning technology

Cloning techniques include different ways of producing and multiplying cells or whole organisms, e.g. plants or animals. The technology can be seen as a sophisticated version of the traditional cultivation technology for animal and plant cells. A basic technique of the technology is cell fusion. *The fused cells contain the nuclei - and hence the genetic information - of both fused cells (K2).*

An important application of cell fusion technique known in 1989 was the production of monoclonal antibodies. So called monoclonal antibodies will probably be important both in therapy of infection diseases and in their diagnostics. Antibodies are key ele-

ments of animal immune systems. They are a defense mechanism which has evolved primarily, it seems, to protect the animals from the ravages of infection by foreign organisms (Moses and Moses 1995, 104). The immune system is based on the existence of large numbers of cells called T- or B-lymphocytes and monocytes. There may be trillions of them in every human being. These cells respond to the presence of antigens, comprising mostly proteins not found within the body of that individual.

The response is based on special proteins called antibodies. The two interacting proteins (the antigen and its antibody) possess complementary structures which allow a precise fit and hence confer specificity.

Antibodies are produced by B-lymphocytes: each B-cell has no more than one type of antigen-receptor protein but every animal and every human being possesses enormous numbers of different types of B-cell, each with its own specific receptor/antibody.

Suppose an infection occurs for the first time in an individual's life. They activate the appropriate B-cells to produce by dividing large numbers of so called plasma cells, each one of which actively secretes that same antibody. This happens in the course of few days (the primary immune response). After the attack of antigens, special cells called memory cells remain in tissues: they "remember" the earlier contacts with that antigen and respond with the production of the required antibody much more rapidly and in much larger amounts than was case on the first contact (secondary immune response).

The idea of traditional vaccines has been to evoke primary immune response with weakened infectious organisms. Alternatively, antibodies (antitoxins) might be prepared in advance and stored. In this endeavour, new cloning technology has proved to be very useful. With traditional methods it is possible to isolate and cultivate correct B-cells. The problem is that b-cells can undergo only a limited number of cell divisions before they die. The growth of cells on a scale necessary for generating usable amounts of antibody requires them to be effectively immortal. They have to be able to go on growing and dividing, and secreting their particular antibody, as long as essential nutrients are provided for them.

The scientific breakthrough in the antibody production based on the new *cloning technology was made by fusing antibody producing cells with cancerous lymphocytes (myeloma cells) (K2a)*. Some of the fused cells were immortal and produced the antibody. It is possible to culture those so called hybridomas on a large scale in a manufacturing process for antibody production. *The product is called "monoclonal antibody" because it is produced as a single, pure substance from a single clone of cells (K2a).*

### 3. Sequencing techniques of nucleic acids and gene libraries

The sequencing technologies are closely linked with the recombinant DNA - technology. The advent of methods for the sequencing of DNA has radically changed the un-

derstanding of gene structure. By the beginning of 1990s, it was already *routine to sequence any newly isolated DNA fragment of interest (K3)*. Two methods were used: the dideoxy or chain termination method of F. Sanger and the chemical cleavage method of A Maxam and W. Gilbert (Wilson and Walker 1994, 142). Both methods are based on the high resolution electrophoresis of four sets of radioactive oligonucleotides produced from the DNA to be sequenced. The chemical cleavage method is now used less frequently.

For one version of the Sanger method, single stranded DNA is required. This is readily obtained by cloning the DNA in bacteriophage M13. The attraction of M13 was that it provides a convenient way to generate large quantities of single stranded DNA, all containing a piece of "foreign" DNA to be sequenced. Sanger sequences may also be carried out using double-stranded DNA using pUC plasmid. Some deoxyribonucleoside triphosphates that must be provided for DNA synthesis are radioactively labeled.

The development of *automated sequencing techniques (K4)* has made possible the projects like HUGO and GENOME. One automatic method involves the use of dideoxyribonucleotides labeled with coloured or fluorescent groups. After a standard Sanger reaction all four samples are run on the same track of an electrophoresis gel, and an optical sensor further down the gel detects the passage of each fragment of DNA and identifies whether it has terminated by ddA (adenine), ddC (cytosine), ddG (guanine) or ddT (thymine) from its colour or wavelength of fluorescence. The output from the sensor can be fed directly into a computer.

The most difficult part of genetic manipulation is not the cloning of DNA, but the isolation of the particular piece of DNA to be cloned (Wilson and Walker 1994, 148). If the aim is to clone a gene then it is helpful to have as much information as possible about the gene product. Usually this product is a protein and ideally antibodies to the protein should be available for detection of the protein. If the amino acid sequence of a protein is known, there is no need to prepare a cDNA probe for its gene.

Frequently an attempt is made to isolate the mRNA transcribed from a desired gene. When a fraction containing the desired mRNA has been identified, it is used to direct the synthesis of DNA molecules complementary to all of the mRNA in that fraction. During maturation of mRNA in eukaryotes, the introns are excised from the molecule, leaving only the exons spliced together; it is this spliced molecule that is used to make cDNA. Genes also have regions flanking them that are of importance in their expression and are not transcribed as part of the mRNA. When a complete gene must be isolated, cDNA can be used as a probe to search through a gene library for the desired gene.

*Gene libraries are constructed by isolating the complete genomic DNA from a cell, and cutting it almost randomly into fragments of the desired average length (K5)*. This can be achieved by partial restriction with an enzyme that recognizes tetranucleotide sequences. The mixture of fragments is ligated with a vector, and cloned. If enough clones are produced there will be a very high chance that any particular gene will be

present in at least one of the clones. Such collection of clones is known as a gene library. A cDNA library can be created similarly by cloning cDNA prepared from the total mRNA of a tissue.

#### 4. Polymerase chain reaction technology and its possible generalizations

According to Watson et al. (1996), the *polymerase chain reaction technique (PCR)(PI)* devised by Gary Mullis in the mid 1980s has revolutionized molecular genetics by making possible a whole new approach to the study and analysis of genes. The use of PCR is closely linked with recombinant DNA technology. PCR was developed as an extension of recombinant DNA technology, and it is e.g. extensively discussed in major text-book Recombinant DNA (Watson et al 1996). Because the future applications of PCR seem to be manifold and may not be restricted in the area of recombinant DNA technology or even molecular genetics (general applications in nanotechnology in multiplication of polymers), it is reasonable to call PCR a generic technology instead of a technique.

The first applications of PCR technology have been in molecular genetics. A major problem in analysing genes is that they are rare targets in complex genome. Many techniques are used to overcome this problem: different techniques of cloning technology and recombinant DNA-technology (e.g. methods for detecting specific DNA sequences). The polymerase chain reaction has changed all this by enabling to produce enormous numbers of copies of a specified DNA sequence. DNA polymerase uses single-stranded DNA as a template for the synthesis of a complementary new strand. These single stranded DNA templates can be produced by heating double-stranded DNA to temperatures near boiling (Watson et al 1996 p. 80). DNA polymerase also requires a small section of double-stranded DNA to initiate ("prime") synthesis. The primers define the specific DNA-codes of the regions which are multiplied.

After the synthesis of complementary DNA-strands the reaction mixture is again heated to separate the original and newly synthesized strands, which are then available for further cycles of primer hybridization, DNA synthesis, and strand separation. A possibility which makes PCR a real generic technology with promising potential applications outside the area of molecular genetics is, that in principle the idea of PCR is not only usable in the multiplication of DNA or RNA. *Any double-stranded polymer with completing strands is a potential target for multiplication(EI).*

In the present state of the art, PCR technology can be used to diagnose all properties which are visible in genetic code e.g. PCR-products can be sequenced directly in identification of genes; mutations e.g. those producing cancer can be detected; DNA typical to bacterial or viral infections can be detected; PCR amplification is used for sex determination of prenatal cells; and PCR can be used in evolutionary studies to determine the degree of relatedness between species (Watson et al. 1996, 88-95)

## 5. Protein and enzyme techniques

Twenty amino acids varying in size, shape, charge and chemical reactivity are found in proteins and each has at least one codon in the genetic code. Proteins are based on chains of amino acids (polypeptide chains). Enzymes are special kinds of proteins which function as catalysts. One focus of *protein and enzyme techniques* (K6) is to uncover primary structures (sequences of the amino acid residues) (K6a), secondary structures (localized folding of polypeptide chain due to hydrogen bonding) (K6b), tertiary structures (the overall folding of a polypeptide chain, which is stabilized by electrostatic attractions and by weak van der Waals' forces) (K8c) and quaternary structures (associations of two or more polypeptide chains) (K6d) (Wilson and Walker 1992, 167-169). Another focus of protein and enzyme technologies is to uncover the activity of proteins and enzymes and the impacts of their e.g. catalytic activities.

## 6. Fermentation and cell, tissue or organ culture technology

In vitro techniques, which involve the incubation of biologically derived material in artificial physical and chemical environments. The promotion a limited degree of growth, differentiation and development in cell, tissue and organ culture of animals and plants. According to the evaluation of the interviewed expert, *fermentation and cell and tissue techniques* (B1) are base technologies of the new biotechnology.

## 7. Microscopy

Biochemical analysis used to be accompanied by *light and electron microscopic examination of tissue, cell or organelle preparations to evaluate the integrity of samples and to correlate structure with function* (B2). Microscopy has served two independent functions of enlargement and improved resolution (the rendering of two separate objects as separate entities) (Wilson and Walker 1995, 41). Light and electron microscopes may work either in a transmission or scanning mode depending on whether the light or electron beam passes through the specimen and is diffracted or whether it is deflected by the specimen surface. *New very effective microscopes Scanning Tunneling Microscope (STM) and Atomic Force Microscope can discern even single atoms* (P2). Heinrich Rohrer and Gerd Binnig got the Nobel Prize in 1986 based on the invention of the STM.

## 8. Radioisotope techniques

Auxiliary technology. *Radioisotopes have been very widely used in the study of the mechanisms and rates of absorption, accumulation and translocation of inorganic and organic compounds by both plants and animals* (B3). Radioisotopes are frequently used for tracing metabolic pathways. This usually involves adding a radioactive substrate (including e.g. H<sub>3</sub>, C<sub>14</sub>, P<sub>34</sub>, I<sub>123</sub>), taking samples of the experimental material at various times, extracting and chromatographically, or otherwise, separating the products (Wilson and Walker 1994, 266).



## 9. Centrifugation techniques

Auxiliary technology. *Centrifugation separation techniques are based upon the behaviour of particles in an applied centrifugal field (B4)* and assume that the parameters of the molecules under investigation, such as the relative molecular mass, shape and density, may be related to the behaviour of those molecules in gravitational field (Wilson and Walker 1992, 275). Centrifugation techniques are of two main types. Preparative centrifugation techniques are concerned with the actual separation, isolation and purification of, for example, whole cells, subcellular organelles, ribosomes, nucleic acids and viruses, for subsequent biochemical investigations. Very large amounts of material may be involved when microbial cells are harvested from culture media. In contrast, analytical centrifugation techniques are devoted mainly to the study of pure, or virtually pure, macromolecules or particles. They require only small amounts of material and utilize specially designed rotors and detector systems.

## 10. Spectroscopic techniques

Auxiliary technology. An understanding of the properties of electromagnetic radiation and its interaction with matter leads to *the recognition of the variety of types of spectrum (B5)*, and consequently spectroscopic techniques. Each region of the electromagnetic spectrum (gamma, X-rays, ultraviolet, visible, infrared, microwaves and radiowaves) has different types of interactions and needs different types of instrumentation for applications in biotechnology.

## 11. Mass spectrometric techniques

In order for the mass spectrometry to identify different chemical structures it is necessary *to perform the kind of experiment that causes the molecular entity to disintegrate and produce fragment ions each of which is represented by a peak in the result spectrum (P3)*. The mass spectrum is essentially dependent upon the thermodynamic stability of the ions produced and collected during a mass spectrometric experiment. The variety of mass spectra that may be obtained range from a single peak to quite complicated patterns of peaks representing various fragments of the original species. Single peak spectra are of particular value in the determination of very accurate molecular masses.

## 12. Electrophoretic techniques

The term electrophoresis describes the migration of a charged particle under the influence of an electric field. Many important biological molecules such as amino acids, peptides, proteins, nucleotides and nucleic acids, possess ionisable groups and, therefore, at any given pH, exist in solution as electrically charged species. Provided the electric field is removed before the molecules in the sample reach the electrodes, the *components will have been separated according to their electrophoretic mobility (B6)*.

### 13. Chromatographic techniques

Auxiliary technology. The basis of all forms of chromatography is the stable partition of compound between two immiscible phases at a given temperature. All chromatographic systems consist of the stationary phase, which may be a solid, gel, liquid or a solid/liquid mixture that is immobilised and the mobile phase. *The choice of stationary and mobile phases is made so that the compounds to be separated have different partitions(B7)* (distribution coefficients Wilson and Walker 1992, 463). For example in column chromatography, the stationary phase is packed into a glass or metal column and the mobile phase is passed through the column either by gravity feed or by use of pumping system or applied gas pressure.

### 14. Electrochemical techniques

Auxiliary technology. At one time the only piece of electrochemical apparatus used commonly in biochemistry was the pH electrode (Wilson and Walker 1992, 535). The transformation of chemical energy into electrical energy (an vice versa) of living systems have, however, presently provided interesting techniques e.g. in the measurement of the concentrations of biologically important substances. Perhaps the most promising applications are biosensors. *A biosensor is an analytical device consisting of a biocatalyst (enzyme, cell or tissue) and a transducer, which can convert a biochemical signal into a quantifiable electrical signal (P4).*

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